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GEORGE OTIS SMITH, DIRECTOR

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BULLETIN 355

THE MAGNESITE DEPOSITS OF CALIFORNIA

BY

FRANK L. HESS

WASHINGTON
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THE MAGNESITE DEPOSITS OF CALIFORNIA.

By Frank L. Hess.

GENERAL REMARKS.

INTRODUCTION.

Magnesite, or magnesium carbonate, ordinarily occurs in veins or in masses replacing other rocks rich in magnesia, though it seems probable that a few isolated and impure deposits in Quebec are of sedimentary origin. (See p. 53.) Although it can hardly be classed as a common mineral, it exists in comparatively large deposits at many places in various parts of the world. The principal foreign deposits now worked are in Austria, Greece, India, Italy, Norway, Russia, and South Africa. Other deposits which are either not worked or from which the output is small occur in Africa, Australia, British Columbia, Lapland, Mexico, Quebec, and Venezuela.

In the United States the only important deposits known are in California. Small veins of mineralogic interest only have been noted in Pennsylvania,[a] Maryland,[b] and Massachusetts,[c] and veins of unknown extent are reported to exist in Nevada and Arizona.

The Maryland and Pennsylvania deposits were at one time worked in a small way, the product being used for making Epsom salts (magnesium sulphate) and other chemicals, but magnesite from Austria, Greece, and South Africa can now be imported so cheaply that it no longer pays to operate them.

In California the deposits are scattered along the Coast Range from Mendocino County, and possibly farther north, to a point south of Los Angeles, and along the western slope of the Sierra Nevada from Placer County to Kern County. (See Pl. I.) Deposits are worked in Sonoma County near Cloverdale, in Santa Clara County near Livermore, and in Tulare County near Porterville. Mines were formerly operated in Chiles and Pope valleys, Napa County, and

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[a] Frazier, P., jr., Lancaster County: Second Geol. Survey Pennsylvania, Vol. CCC, 1880, pp. 89, 97, 176–179, 196.

[b] Bascom, F., The geology of the crystalline rocks of Cecil County: Cecil County report, Maryland Geol. Survey, 1902, pp. 96–97.

[c] Dana, J. D., A system of mineralogy, 6th ed., 1892, p. 275.

considerable prospecting and preparatory work has been done at several other places with desultory production.

The field work on which the present article is based was done in November, 1905, and during the winter of 1906–7.

The literature of magnesite deposits is scanty, and aside from paragraphs and short general articles appearing in current periodicals from time to time, but little has been published on the California magnesite deposits.

COMPOSITION, PROPERTIES, AND USES.

GENERAL CHARACTER.

Magnesite is a carbonate of magnesium ($MgCO_3$), having, according to Dana,[a] a specific gravity of 3 to 3.12, and a hardness of 3.5 to 4.5. It is somewhat heavier than calcite (2.714 specific gravity), and is about one-third harder, the hardness of calcite being 3. It contains 52.4 per cent of carbon dioxide (CO_2) and 47.6 per cent of magnesia (MgO).

As it occurs in the California deposits, magnesite when comparatively pure is ordinarily a beautiful, white, fine-grained rock, with a conchoidal fracture that looks like a break in china. (See Pl. II.) It will take a fine polish and when so treated is an opaque white. Locally a portion of the magnesite occurs in a fine powder in what seem to be decomposition cavities and upon surfaces exposed to weathering.

MANUFACTURE AND USE OF CARBON DIOXIDE.

Magnesite gives off carbon dioxide on strong heating and is used in preference to limestone for the production of this gas, as it contains a much greater proportion than calcium carbonate, which carries but 44 per cent. Other advantages of magnesite are that the residual magnesia left after calcination is more valuable than lime, and that the amount of heat required to drive off the carbon dioxide is much less.

Considerable amounts of liquid carbon dioxide are manufactured in Oakland from magnesite. As made at the Western Carbonic Acid Gas Company's plant at Sedan (Emeryville post-office), a suburb of Oakland, the magnesite is fed into a kiln with about one-tenth its weight of coke, and the gas from the combustion of the coke, together with that driven off from the magnesite, is pumped into scrubbers, of which there are three, filled with broken limestone to counteract any sulphuric acid, and washed with sea water. The use of sea water rather than fresh water is merely an economy. The gas then passes to an absorption tower where it comes into contact with a sprayed solution

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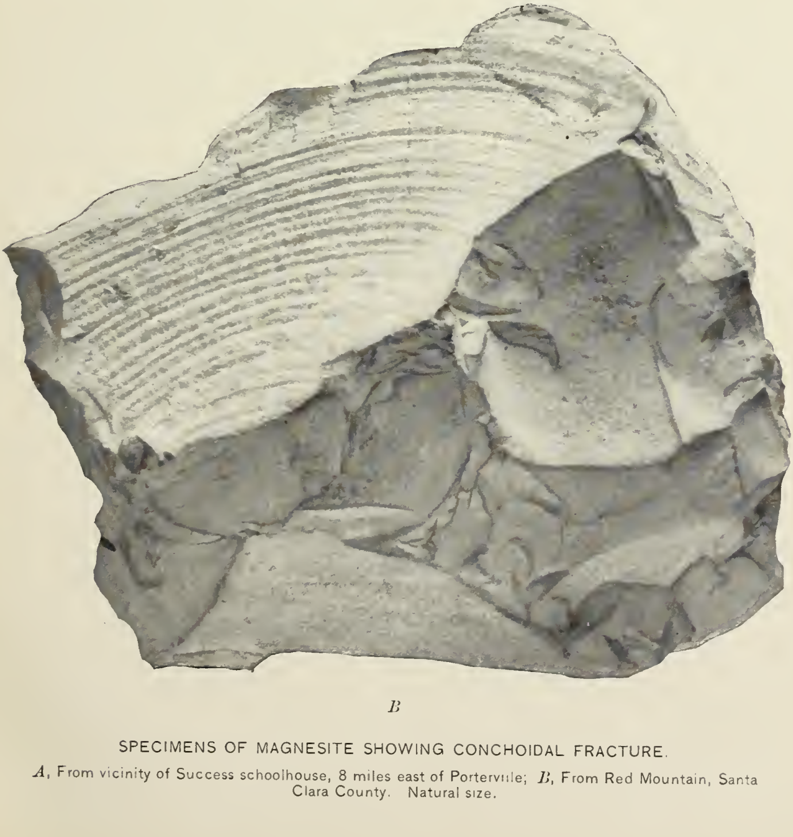
[a] Dana, J. D., A system of mineralogy, 6th ed., 1892, p. 274.

A



B

SPECIMENS OF MAGNESITE SHOWING CONCHOIDAL FRACTURE.

A, From vicinity of Success schoolhouse, 8 miles east of Porterville; *B*, From Red Mountain, Santa Clara County. Natural size.

of potassium carbonate, by which it is absorbed. The "loaded solution" is then pumped into boilers where it is raised to a temperature just below the boiling point of water. The solution gives up its gas and is pumped back to the absorption tower for another load, while the gas is pumped through cleansing tanks and cooling pipes to a gasometer. It is then liquefied by a three-step compressor and run into steel cylinders, holding 25 to 60 pounds each, for shipment. In this process the weight of gas obtained is about 50 per cent of the weight of the magnesite used. The accompanying diagram (fig. 1) will probably make the steps clear. The gas is shipped throughout the Pacific coast and Southwestern States. It is used in refrigeration and in making soda water and other carbonated beverages. The magnesia left as a residue is shipped to paper mills in Oregon, where it is used, after being changed to a sulphite, in the digestion and whitening of wood pulp for paper. This is the chief use to which California magnesite is put, and almost the entire output of the Porterville deposits eventually finds its way to these mills.

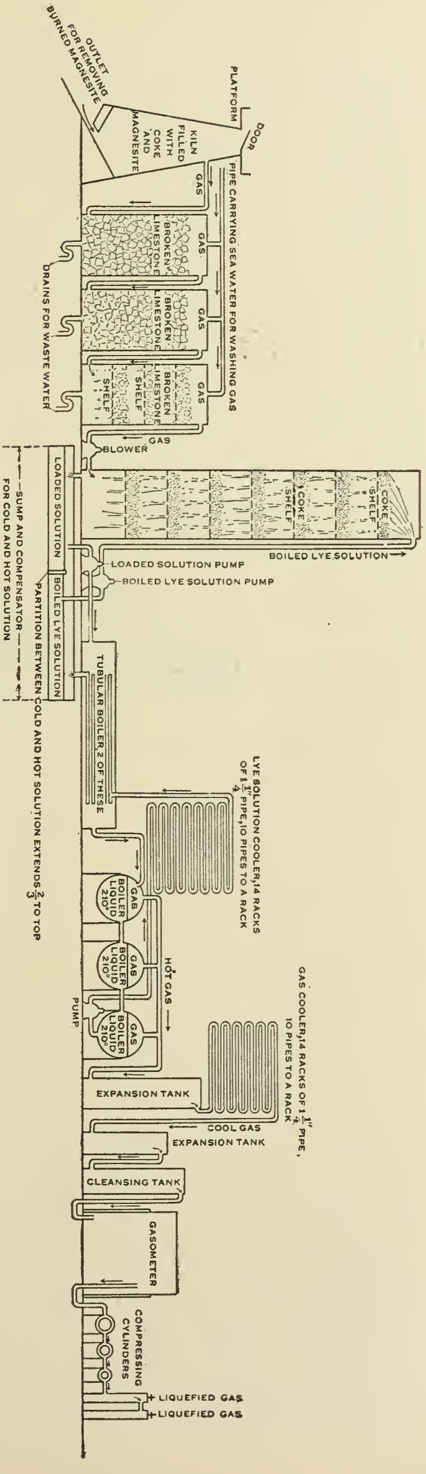


Fig. 1.—Diagram of Western Carbonic Acid Gas Company's plant at Sedan, Cal.

CALCINATION OF MAGNESITE.

Among men engaged in calcining magnesite, a difference of opinion has existed as to the temperature at which the carbon dioxide can be driven off. In recent experiments Otto Brill[a] has determined this point and made a number of interesting discoveries as to the behavior of magnesite when heated. His experiments were carried on with small amounts of carefully prepared and purified materials, so that his results are not exactly analogous to those that would be obtained by using the raw natural material. He showed that calcium carbonate (as ordinary limestone) gives up all of its carbon dioxide at 825° C. (1,517° F.), but that magnesium carbonate (magnesite) begins to give off carbon dioxide at about 237° C. (465° F.). A certain quantity is given off at this temperature, after which little or none is exhaled until the magnesite is heated to 250° C. (482° F.), at which point another certain quantity escapes. On raising the temperature a third partial dissociation point is reached at 265° C. (509° F.). Other such stages were marked at various points, and these were considered to show the successive formation and breaking up of various basic carbonates. The last of the carbon dioxide is given off at 510° C. (950° F.), a temperature much below that needed to calcine limestone. Brill's table showing the different carbonates formed is given below. The reduction to the Fahrenheit measurement of temperature is added by the writer of this paper.

Basic carbonates formed in burning magnesite.

	Calculated MgO.	Obtained MgO.	Dissociation temperature.	
			°C.	°F.
	Per cent.	*Per cent.*		
$10MgO, 9CO_2$	50.64	50.58	265	509
$9MgO, 8CO_2$	50.79	50.98	295	563
$8MgO, 7CO_2$	51.20	51.37	325	617
$7MgO, 6CO_2$	51.51	51.69	340	644
$6MgO, 5CO_2$	52.36	52.35	380	716
$5MgO, 4CO_2$	53.41	53.03	405	761
$7MgO, CO_2$	86.53	86.31	510	950

The temperature at which magnesite gives up the last of its carbon dioxide, 510° C., is below a red heat, but the time required to drive off all of the gas is not stated by Brill, and this, of course, would vary with the size of the material used. The important point, however, is that at this temperature all of the carbon dioxide will be driven off, so that, although higher heating will undoubtedly remove the gas more quickly, because the heat will reach the inner portions of fragments sooner, it ordinarily means a waste of fuel.

After magnesite is calcined the resultant magnesia takes up CO_2 from the air, again returning to the form of magnesite or magnesium carbonate, but it does this so slowly that it can not compete with lime or hard plasters in structural work.

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[a] Ueber die Dissoziation der Karbonate der Erdalkalien und des Magnesiumkarbonates: Zeitschr. anorg. Chemie, vol. 45, part 3, June, 1905, pp. 277-292.

MAGNESIA BRICK, SHAPES, AND CRUCIBLES.

Calcined magnesite (magnesia) is used for making refractory brick and shapes for furnace linings. These products will stand exceedingly high temperatures, above any heat that can be obtained in regenerative furnaces, so that they are much used for lining electric furnaces. A considerable number are also employed in cement kilns and fire boxes for burning crude oil, uses in which intense and long-continued heat must be endured. They are also exceedingly resistant to corrosion by basic slags and most molten metals. These qualities make them desirable for linings in furnaces used for copper smelting and in the manufacture of basic steel. In the latter process the lime added to remove phosphorus and silica attacks clay or silica fire brick severely, but magnesia brick are little affected.

Furnaces built of magnesia brick or shapes must, to prevent cracking, be heated evenly and as gradually as possible, so that the inner ends will not be raised to a high temperature while the outer portions are still cold. The same care must be used in cooling off, and the furnace must lose its heat gradually and evenly if the shapes are to be preserved. Sometimes considerable trouble is caused by the swelling of magnesia brick and shapes on heating and a corresponding shrinkage on cooling, and copper converters are reported to have burst from this cause. This difficulty seems to be due largely to insufficient sintering, for very strongly sintered brick are said to give little trouble.

A plant for the manufacture of magnesia brick was erected at Clinton, a suburb of Oakland, in 1905, and is still in operation. Most of the magnesia brick made in this country are manufactured from European magnesite. Some magnesia brick of foreign manufacture were formerly imported each year, but none are shown in the customs returns for 1907.

Magnesia crucibles are made of various forms and different degrees of fineness. Crucibles made from pure magnesia have much the appearance of fine biscuit ware. If heated to incipient melting they have the appearance of translucent glass. When the ordinary European commercial calcined magnesite is used for crucibles, it has little strength above a red heat, but crushes in the tongs like so much putty.[a] Dr. Oliver P. Watts, in a long series of experiments in the preparation of metallic alloys, used magnesia crucibles as linings for carbon or graphite crucibles to prevent the absorption of carbon by the charge, and found that they answered the purpose excellently. In such crucibles alloys of iron with aluminum, cobalt, chromium, copper, manganese, molybdenum, nickel, silicon, silver, tin, titanium,

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[a] Watts, Oliver P., in letter to author.

and tungsten were made. Chromium, silicon, and titanium, when forming 10 per cent or more of the charge, seemed to attack the linings, to judge from the failure of a number of them.

"These linings are extremely refractory, so that the maximum temperature at which they can be used is fixed not by their melting, but by another phenomenon, the reduction of the magnesia by carbon."[a] The carbon attacks the magnesia and corrodes it, especially if iron oxide be present, in which case, under very high temperatures, the iron oxide is volatilized and, coming into contact with the graphite crucible, is reduced and collects as microscopic spheres of iron. These grow and roll down the sides, carrying absorbed graphite, which vigorously attacks the magnesia after the equation $MgO + C = Mg + CO$. At a lower temperature this action is reversed, and for this reason magnesium can not be obtained from magnesia by reduction with carbon.

Magnesia crucibles made under such temperatures are white, even when much iron oxide is present in the raw materials, for the iron oxide is volatilized and driven out.[b] Mr. A. J. Fitzgerald, of Fitzgerald & Bennie, Niagara Falls, N. Y., states in a letter of March 21, 1908, to the writer, that his firm melts charges of 6 or 7 pounds of alloys in magnesia crucibles in electric furnaces by withdrawing the charge through the bottom. Cracking from change of temperature is not likely to take place in small, well-fused magnesia crucibles.

Much mystery has been attached to the binders used in making magnesia brick, shapes, and crucibles, to cement the particles together when burned. It is a common belief among persons handling magnesite that to make brick which will hold together when burned it is necessary to use magnesite containing impurities consisting of iron oxides or serpentine. It is undoubtedly true that such impurities will allow the sintering of brick at very much lower temperatures than are necessary with pure magnesite, but they also make the brick more fusible and more easily corroded by molten materials. A pure magnesia brick demands a very high temperature for sintering, but bricks can be made without the impurities mentioned or others, and when so made are extremely refractory. Dead-burned magnesite—that is, magnesite from which the CO_2 has been entirely driven off—has little or no plasticity, so that it is hard to handle. It is said that its plasticity is much improved by using partly calcined or caustic magnesite with it. Heavy pressure will bind the material sufficiently to allow it to be sintered; 240 tons per brick is used in the works at Snarum, Norway.[c]

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[a] Letter cited. See also paper by Doctor Watts, The action of carbon on magnesia at high temperatures; Trans. Am. Electrochem. Soc., vol. 10, 1907, pp. 279–289.

[b] Watts, O. P., op. cit., p. 287.

[c] Daumann, E., Magnesit fran Snarum: Bihang till Jern-Kontorets Annaler for 1905, Stockholm, 1905, pp. 222–225.

Magnesia may be melted to a glassy substance in an electric furnace, but when so treated contains many bubbles. It seems highly probable that it would be profitable to sinter magnesia brick and similar products in an electric furnace, where electric power is as plentiful as it is in California.

MAGNESIUM CARBONATES.

For some of the purposes to which magnesite is rather extensively put, dolomite, the calcium magnesium carbonate, may be used, as in the making of magnesia alba levis (light magnesium carbonate) and Epsom salts. The light carbonate is well known as a toilet preparation and is also used in medicine. Mixed with various amounts of asbestos it is used for pipe covering and boiler lagging; 85 per cent of light carbonate to 15 per cent of asbestos is a common proportion. The asbestos is needed to hold the powdery carbonate together. For this purpose water glass (sodium silicate) is also sometimes added to the mixture. The heavy carbonate is sometimes used instead of the light carbonate, in which case the efficiency of the covering is probably diminished owing to the lesser degree of porosity. The light carbonate is said to make an excellent absorbent for dynamite manufacture, as it does not readily allow the nitroglycerine to "sweat" out. Powdered magnesite is introduced to prevent scale in boilers in which sulphurous waters are used, as the magnesium sulphate (Epsom salts) formed is highly soluble.

OXYCHLORIDE CEMENT.

For many years it has been well known that a moistened mixture of magnesium oxide (magnesia) and magnesium chloride will form an exceedingly strong cement, and numerous attempts have been made to use it in manufacturing tiles, artificial stone, flooring, wainscoting, etc. Many of these attempts have met with failure owing to an unlooked-for decomposition of the manufactured product, and this has prevented the industry from becoming important as quickly as had been expected. The failure of the cement seems to be due to the presence of lime either in the magnesium chloride or in the magnesia, which in the form of chloride is hygroscopic and by taking up water swells and destroys the usefulness of the material, and so where magnesite is to be used in the manufacture of cement efforts are made to obtain it as free from lime as possible.

At the Malelane deposits, South Africa, the magnesite is calcined, ground, and mixed with imported German magnesium chloride at the mine and shipped ready for use as cement.[a]

In using the cement for flooring, wainscoting, etc., it is mixed with sawdust or sand and coloring matter to give it the desired tint. It

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[a] Hall, A. L., The magnesite deposits of Malelane: Rept. Geol. Survey, Transvaal Mines Dept., 1906, Pretoria, 1907, pp. 127-132.

may be laid in a continuous sheet over considerable areas and is said to crack much less easily than cement. The use of sawdust makes the material very much lighter in weight than cement, less hard, and more resilient. The surface is commonly waxed and polished, like a wooden floor. At the present time a large part of the Grecian magnesite imported into this country is used for making such floors. The material has also been used for wall plaster, and in specimens seen by the writer would stand severe abuse without breaking.

In these preparations the sawdust particles are well separated, so that the material is in a high degree fireproof. The same mixture is used for making stationary washtubs and for similar purposes.

OTHER USES.

Sintered magnesite tubing of assorted sizes, up to 31.5 inches in length and 2.8 inches in diameter, is regularly made for chemical and electrometallurgical work.

The fusing point of magnesia has been determined by Goodwin and Mailey[a] as about 1910° C. The same experimenters found that the fused material is not acted upon by fused silver, sodium, potassium, or barium nitrates; nor by sodium, potassium, or zinc chlorides, bromides, or sulphate, even after an hour's exposure of a polished surface to their action. Barium chloride has a very slight action on it, but sodium carbonate, potassium sodium carbonate, potassium hydrate, and cryolite attacked the fused oxide energetically. Cold dilute hydrochloric, nitric, and sulphuric acids attack the fused oxide slowly, and concentrated acids are less active than dilute acids.[b] The fused magnesite takes up but little CO_2 from the air, and it is possible that if pure material were used it would be found that there is no recombination with carbon dioxide. In experiments performed by Fitzgerald & Bennie,[c] during which they found specimens to take up 0.42 and 0.63 per cent CO_2, the magnesia used contained 1.10 and 2.48 per cent of lime, respectively, which may have been the combining substance. According to the experiments of Goodwin and Mailey the coefficient of linear expansion of fused magnesia is almost the same as that of platinum, and but little more than that of quartz parallel to the optic axis. They find the coefficient of linear expansion between 120° and 270° C. to be—

$$a_t = 10^{-8}\,[1140 + 0.92\ (t - 120°)],$$

while for platinum they quote Holborn and Day as giving—

$$a_t = (8889 + 1.274\ t)\ 10^{-9} \text{ for } t = 0° \text{ to } 1000°.$$

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[a] Physical properties of fused magnesium oxide: Trans. Am. Electrochem. Soc., vol. 9, 1906, pp. 92–93.

[b] Op. cit., p. 98.

[c] Discussion of "Physical properties of fused magnesium oxide:" Trans. Am. Electrochem. Soc. vol. 9, 1906, pp. 101–103.

In these formulæ a_t stands for the coefficient of expansion at any given temperature, t standing for temperature.

A coating of crushed magnesite is laid on hearths used for heating steel stock for rolling, to prevent the scale formed from attacking the fire brick of the hearth.

When heated to a high degree magnesia becomes incandescent like lime and the rare-earth oxides. On account of this property numerous efforts have been made to construct an incandescent lamp, similar to the Nernst lamp, which uses a glower made of zirconia and yttria, but not much success has been attained. A patent[a] has been taken out for the construction of electrodes for arc lamps from a mixture containing 90 per cent of magnesia and 10 per cent of iron oxide. Magnesia is a poor conductor of electricity,[b] and the iron oxide is introduced to increase the conductivity. Owing to its nonconductivity magnesite mixed with iron dust has been used for the manufacture of rheostats.[c]

Magnesia has been used for an adulterant in paint, but it has little virtue as a pigment. Its covering properties are poor, and it settles badly in the mixture.

Magnesium (metal) is not obtained from magnesite, but from magnesium chloride, which is obtained in large quantities from the Stassfurt salt deposits in Germany and from sea water at other places.

MARKET FOR CALIFORNIA MAGNESITE.

The market for California magnesite is at present limited to the Pacific coast and Rocky Mountain States, as the necessarily high freight rates, due to the long railroad haul to the eastern portion of the country, preclude its shipment in competition with imported magnesite. Moreover, the California deposits are handicapped in the competition with foreign deposits by the much higher scale of wages paid in this country. Day laborers in California receive $1.50 to $2 for a ten-hour day, and if miners are hired for the work, $2.50 to $3 must be paid. In Hungary the wages paid in 1906 at the works of the Magnesite Company (Limited) were 40 cents per ten-hour day for common labor and 80 cents for foremen.[d] Besides these drawbacks, none of the California veins compare well in size with the reported width of the Hungarian veins. In quality, however, the comparison with the foreign material is favorable; in fact, the California article is ordinarily better.

Magnesite from Porterville now costs about $6.50 per short ton laid down at San Francisco; probably that from the Gilliam Creek (Sonoma County) deposits can be delivered for somewhat less. Pro-

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[a] Lewis J. Jones, letters patent No. 484553, dated October, 1892.

[b] The conductivity of magnesia when heated is treated in the article by Goodwin and Mailey, to which reference has been made (p. 14).

[c] E. W. Gilbert, letters patent No. 439939, dated November 4, 1890.

[d] Private letter.

duction at the Kings River deposits will cost about the same as at Porterville. Magnesite from Sonoma and Napa counties can probably be calcined and laid down in San Francisco at $15 per short ton. Imported magnesite is now (April, 1908) quoted in New York City at $7.25 to $8 per long ton, equal to $6.38 to $7.08 per short ton; calcined magnesite is quoted at $16.75 to $25, and when comparatively free from lime, ground, sells in small lots at the latter price. With this difference in price for calcined magnesite of about $5 to $6 between San Francisco and New York, it seems possible that this product could sometimes be shipped at a profit to the eastern coast of the United States on vessels that would otherwise sail without a full cargo and would for this reason be willing to carry the material at low rates.

In spite of the fact that the California magnesite is ordinarily purer and cheaper, calcined Grecian magnesite is shipped into Los Angeles as "white cement" for use in oxychloride cement.

PRODUCTION.

The production of magnesite in California since 1891, the first date for which figures are available, has been as follows:

Quantity and value of crude magnesite produced in California, 1891–1907.[a]

	Short tons.	Value.		Short tons.	Value.
1891	439	$4,390	1900	2,252	$19,333
1892	1,004	10,040	1901	3,500	10,500
1893	704	7,040	1902	2,830	8,490
1894	1,440	10,240	1903	3,744	10,595
1895	2,220	17,000	1904	2,850	9,298
1896	1,500	11,000	1905	3,933	15,221
1897	1,143	13,671	1906	7,805	23,415
1898	1,263	19,075	1907	[b] 7,762	50,453
1899	1,280	18,480			

[a] Yale, C. G., Magnesite: Mineral Resources U. S. for 1906, U. S. Geol. Survey, 1907. The figures for 1907 were also kindly furnished by Mr. Yale

[b] From this amount 3,234 tons of calcined magnesite, worth $20 per ton, was produced.

IMPORTS OF MAGNESITE AND ITS PRODUCTS.

The imports of magnesite into the United States for the last three years have been as follows:

Imports of magnesite and magnesite products into the United States in 1905, 1906, and 1907.[a]

	1905.		1906.		1907.	
	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.
Magnesia:						
Calcined, medicinal	13,554	$2,778	30,788	$5,689	49,489	$9,005
Carbonate of, medicinal	21,901	1,360	39,487	5,844	85,467	3,994
Sulphate of, or Epsom salts	9,039,099	38,084	5,830,224	22,471	4,532,713	16,256
Magnesite:						
Calcined, not purified	134,595,334	575,355	141,314,682	740,585	151,137,661	688,371
Crude	14,152,466	63,264	39,477,766	122,908	46,878,740	186,988

[a] Figures furnished by Bureau of Statistics.

There is no duty on magnesite or calcined magnesite, nor on the salts of magnesium mentioned in the table. For some reason the calcined magnesite imported in 1907 is declared of much lower value than the market price ($8.11 per ton as compared with $16.75 to $25).

DESCRIPTION OF DEPOSITS.

GENERAL STATEMENT.

The California magnesite deposits, so far as known, all occur as veins in connection with serpentinized magnesian rocks. By far the larger part are in the Coast Range, in the serpentinized rocks that stretch from southern California into Oregon. These rocks, although in few places wholly altered, will be referred to as serpentines, the name by which they are ordinarily known. Those in the Coast Range are probably lower Cretaceous in age[a] and cover large areas, Becker[b] estimating that between Clear Lake and New Idria, a distance of about 200 miles, there are more than 1,000 square miles of serpentine. Through a large part of this area magnesite veins of various sizes are found. Veins large enough to be more or less workable are known to occur at many places in Mendocino, Sonoma, Napa, Alameda, Stanislaus, and Santa Clara counties. Along the western side of the Sierra Nevada magnesite is found in Placer, Fresno, Tulare, and Kern counties, and in southern California in Riverside County.

The serpentines of the Coast Range are ordinarily greenish or bluish, greatly broken and faulted, a solid block a foot in diameter being a rarity in many localities. They are derived from olivine-pyroxene rocks, in which the amounts of the minerals vary in ratio at different localities. Here and there the rocks still carry considerable portions of only partly altered minerals, though the general decay is far advanced. There is great difference, both in the comparative amounts of the original minerals from which the serpentine is formed, and in the degree of serpentinization, even in small areas. Some rocks are almost wholly made up of partially serpentinized olivine, in places carrying chromite and chromic mica, while near at hand other specimens show large quantities of orthorhombic pyroxene. Along the Sierra Nevada the serpentine at the Fresno and Tulare County localities is of a dull drab or brown color and that in Tulare County is much less broken than the Coast Range serpentines.

Magnesite is probably formed both from the breaking down of the serpentine-making minerals and from the serpentine itself. In a specimen from the northeast corner of Santa Clara County enstatite has been replaced by magnesite. Many of the cracks in the olivine are filled by magnesite. These cases seem to show the derivation of

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[a] Fairbanks, H. W., San Luis folio (No. 101), Geologic Atlas U. S., U. S. Geol. Survey, 1904, p. 6.

[b] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, p. 103.

magnesite directly from the original minerals, but the ordinary tendency shown by magnesite bodies is to occur in only those portions of the serpentine which show great decay, the magnesite being probably formed mostly from the serpentine.

Van Hise[a] supposes that in the decay of olivine a third of the magnesium may pass into magnesite, in which case he would write the reaction for olivine containing magnesium and iron in the atomic ratio of 3:1 as follows:

$$\underset{\text{Olivine}}{3Mg_3FeSi_2O_8}+\underset{\substack{\text{Carbon}\\\text{dioxide}}}{3CO_2}+\underset{\text{Water}}{4H_2O}+\underset{\substack{\text{Oxy-}\\\text{gen}}}{O}=\underset{\text{Serpentine}}{2H_4Mg_3Si_2O_9}+\underset{\substack{\text{Magne-}\\\text{tite}}}{Fe_3O_4}+\underset{\text{Magnesite}}{3MgCO_3}+\underset{\text{Quartz}}{2SiO_2}+\underset{\text{Heat}}{k}.$$

Here "k" signifies that heat is liberated.

This equation is largely theoretical, and as a matter of fact little magnetite is found in many of the specimens examined. Hydrated oxides of iron are common, however, and it seems probable that to such an equation water should be added to the unknown amount necessary to hydrate the iron. At the same time it is to be remembered that vastly more carbonated water is ordinarily present than is required to supply the amount demanded by the equation, so that it seems possible that under certain conditions, with this excess of carbon dioxide at hand, the entire amount of magnesium contained in olivine carrying equal numbers of magnesium and iron atoms may pass into magnesite. Such a change may be represented by this equation:

$$\underset{\text{Olivine}}{4Mg_2Fe_2Si_2O_8}+\underset{\text{Water}}{6H_2O}+\underset{\substack{\text{Carbon}\\\text{dioxide}}}{8CO_2}+\underset{\substack{\text{Oxy-}\\\text{gen}}}{4O}=\underset{\text{Limonite}}{2(2Fe_2O_3.3H_2O)}+\underset{\text{Magnesite}}{8MgCO_3}+\underset{\text{Quartz}}{8SiO_2}.$$

Enstatite also alters to magnesite, and in a few specimens is wholly replaced by it. Probably other pyroxenes also form magnesite on weathering.

It seems probable that as a rule both serpentine and magnesite are formed in the process of decay of the original minerals in peridotites and allied basic rocks, and that during the decay of the serpentine the formation of magnesite is continued. In any case the magnesia or magnesian mineral is changed to the carbonate, dissolved by percolating water charged with carbon dioxide, and precipitated in cracks and crevices as veins. The silica is carried away in solution by the water and is often deposited in other veins or with the magnesite veins as opal or quartz.

Many magnesite veins stand out prominently from the surrounding serpentine, as they weather less readily than the serpentine, and also because in the vicinity of a magnesite vein the surrounding serpentine is generally much decomposed and therefore erodes rather easily. The boldness of outcrop and the snowy whiteness of the veins form a

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[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 309.

WEATHERED SURFACES OF MAGNESITE.

A, From Red Mountain, Santa Clara County; *B*, *C*, From locality 4 miles northeast of Porterville. All natural size.

strong contrast with the dull-colored surroundings, so that their occurrence at once attracts the eye.

Surfaces of comparatively pure, even-grained magnesite, exposed to the weather, are in many places fluted by the rain, similarly to limestone under like conditions, but the flutings or channels are much narrower. Other surfaces are covered with sharp-angled irregular projections, due probably to impurities. (See Pl. III.) At Red Mountain, Santa Clara County, earth-covered pieces attacked by percolating water have weathered into designs resembling mud cracks, with the spaces between the cracks convex and a little over half an inch across. (See Pl. IV, *B*.)

In many of the larger veins there is a central portion of comparatively pure magnesite, and in the same veins on one or both sides there may be many inclusions of serpentine. This mixed condition of the magnesite and serpentine is common in the large veins seen along the Coast Range. Small inclusions of serpentine in many places extend well into the vein. Toward the side the inclusions form a gradually larger proportion of the mass until the magnesite appears only as a great number of small veins in the broken serpentine. Or, if the main mass is approached from the side, as along a tunnel, a stockwork of small veins first appears, growing thicker toward the large vein, until the larger part of the mass is magnesite and the pieces of the serpentine are so separated as to become inclusions in the magnesite. This may result from two forms of growth. If any particular group of anastomosing veins grows greatly, the fragments between the veins become so separated that they lose their predominance as compared with the magnesite, and the magnesite forms the greater part of the mass. In the other form of growth the serpentine fragments may be partly or wholly replaced by magnesite. Still other large veins and masses are clear magnesite from the center to one or both sides, either of which may be formed by much slickensided faults.

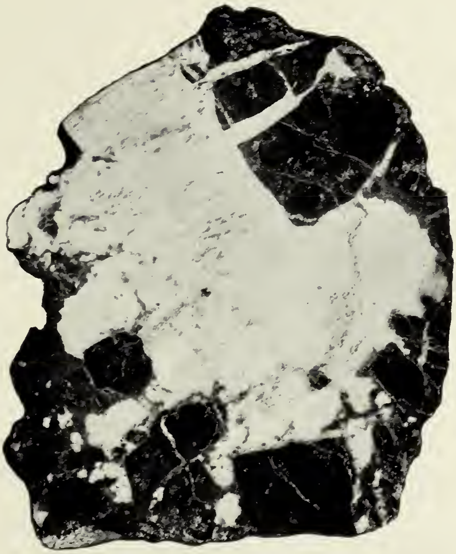
There is considerable difference in the purity of the veins at different places. Some are beautifully white and contain but a small percentage of foreign matter; others contain iron oxides, silica, clay, or serpentine in varying amounts and proportions.

Near the veins the serpentine has almost without exception lost its normal color and is badly rotted and porous as the result of its decomposition by percolating surface waters. The rock shrinks through the gradual removal of its components and the magnesite fills the enlarging spaces between the fragments. The magnesite produced through the decomposition of serpentine occupies about four-fifths of the space of the original rock, so that a magnesite vein may be and probably is formed very largely from the serpentine which formerly occupied the space now filled by the vein, the remainder coming from the rock in a comparatively narrow zone on each side. The large width of some of the veins may thus be explained, by supposing that they occupy the spaces made by the disintegration of the serpentine almost as fast as they are left, rather than natural fissures or cracks in the rocks. The veins are thus, in a sense, partly residual from the serpentine. In specimens collected fragments of serpentine are to be seen in various stages of decomposition and replacement; in others the fragments are as sharp angled as if freshly broken. Belts of disintegration naturally occur along the channels with greatest circulation of water, generally coincident with the larger faults. Every crack and joint along the line makes a feeder for the trunk channels. Among these reticulations the same process of decomposition is going on, and in places abrupt enlargements of the veins occur, making so-called "bowlders" of magnesite, which may be 2 or 3 feet or even more in diameter and nearly equidimensional. The formation of such a deposit, on a small scale, is shown in Pl. IV, *A*. This lack of linear extension in the small deposits, together with the number of faults known to cut the Coast Range serpentines in every direction, makes the following of veins by widely separated outcrops very uncertain, as the outcrops may be, and many of them are, distinct deposits, though they happen to have a certain alignment. Abrupt terminations are known to occur in the large deposits as in the smaller ones, and it is unsafe to expect the same continuity as would be thought probable in a quartz vein of equal width.

Two modes of precipitation of magnesite from solution suggest themselves. Brucite ($Mg(H_2O)_2$), formed through the decomposition of magnesian minerals without carbonation, may take the CO_2 from carbonated water carrying magnesite and thus precipitate both the newly formed molecule and the magnesite carried in solution, owing to the loss of excess CO_2 in the water; or magnesite may be precipitated from carbonated water owing to the loss of CO_2 through evaporation. Nothing resembling brucite has been seen, either in microscopic sections or in hand specimens, so that the latter hypothesis seems more likely, though possibly it applies only to the veins deposited in more open places, the former process going on in the small threadlike veins.

Little is known of the depth to which the veins extend. If they are formed through the agency of percolating surface water, which seems most likely, the manner of precipitation probably has little to do with the depth to which they extend. It seems fair to assume that the deposits may be found down to the limit of easy circulation of these waters, a depth of several hundred feet in favorable localities, their size being modified by the time through which such circulation has existed, by differences in the hardness or composition of the rock, etc. Faulting is as likely to cut the veins off in depth as in length.

Cinnabar and chromite occur in the serpentines in the neighborhood of many of the magnesite deposits.



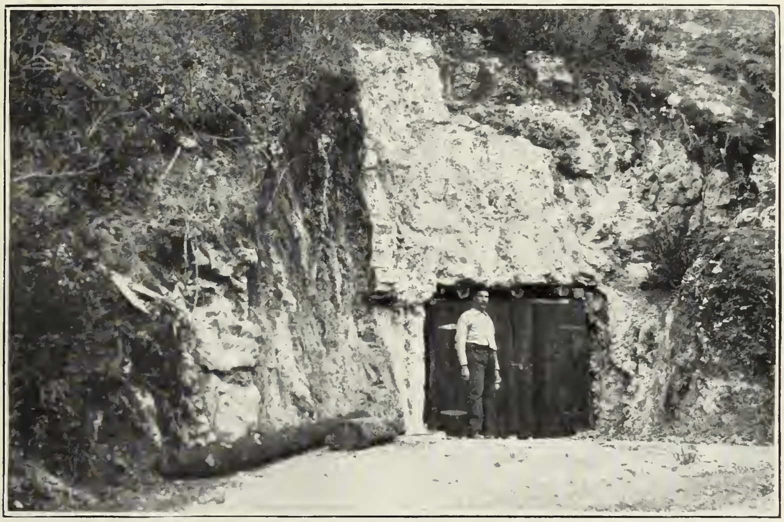
A. SMALL IRREGULAR VEIN OF MAGNESITE IN SERPENTINE.

From Red Mountain, Santa Clara County.

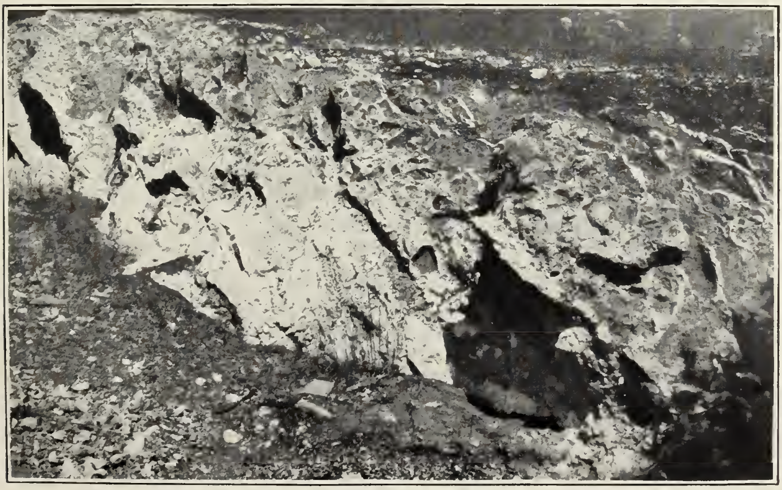
B. MAGNESITE WEATHERED UNDER SEVERAL INCHES OF CLAY.

The surface is soft. From Red Mountain, Santa Clara County.

A. OUTCROP OF MAGNESITE ON HIXON RANCH, MENDOCINO COUNTY.



B. ENTRANCE TO LOWER TUNNEL ON SONOMA MAGNESITE COMPANY'S CLAIM, NEAR CAZADERO.



C. OUTCROP OF MAGNESITE VEIN ON WALTERS CLAIM, POPE VALLEY.

The face exposed is about 6 feet high.

THE COAST RANGE OCCURRENCES.

The individual California deposits will be treated by counties, beginning with the northernmost in the Coast Range and going southward to southern California, then northward along the Sierra Nevada.

MENDOCINO COUNTY.

Hixon ranch deposits.—On the Hixon ranch, on the east side of Russian River, 12 miles north of Cloverdale, there are a number of outcrops of magnesite, about 600 feet (barometric measurement) above the river, near the crest of a long ridge whose east side slopes steeply to a deep canyon and whose west side falls away more gently toward Russian River. The ridge at this place is formed entirely of serpentine, and it has broken off in successive blocks which are faulted downward toward the river, about 1½ miles away. Behind the fault blocks are hollows in which ponds form. The wagon road following the river crosses the serpentine, which is here reduced to mud and is excessively wet much of the time, owing probably to water that follows the faults and oozes out at this place.

The principal outcrop of magnesite (see Pl. V, *A*) is almost at the top of the ridge. It is apparently 15 to 20 feet thick and 30 feet long, standing between 4 and 5 feet above the surface, with a westerly dip. On the west side of the vein slickensides in two directions are plainly marked. Two smaller outcrops within 100 yards S. 35° E. (magnetic) from this one may be a continuation of the same vein.

Several other veins from a few inches to 1 foot thick outcrop within a few feet of the main exposure, and 200 feet farther west are a number of smaller, less pure, and less continuous veins. It seems probable that the veins are not continuous to great depth owing to the recency of the faulting, by which they would have been cut off.

No work has been done on any of the veins.

The magnesite in the main outcrop is white and remarkably pure, especially as regards its freedom from lime. A partial analysis by A. J. Peters, at the St. Louis laboratory of the United States Geological Survey, gave the following result:

Partial analysis of magnesite from J. M. Hixon ranch.

[Solution of air-dried material.]

Silica (SiO_2)	0.41
Alumina (Al_2O_3)	.28
Ferric oxide (Fe_2O_3)	.12
Lime (CaO)	.03
Magnesia (MgO)	47.16
Carbon dioxide (CO_2)	51.88
	99.88

As occasionally noted at other places, the magnesite shows shrinkage cracks (see Pl. VI, *A*) as if it had shrunk after deposition. This suggests the probability that it may have been deposited in the form of a hydrous carbonate.

Smaller deposits are said to occur near by, but they were not seen by the writer.

SONOMA COUNTY.

Creon deposit.—Four miles north of Cloverdale a number of magnesite veins outcrop in extremely irregular serpentine dikes, on a spur running southwestward from the mountains on the east side of the Sonoma Valley. The deposits are about 1,000 feet (barometric measurement) above Cloverdale, on a steep road, but the haul is all down hill.

The dikes in which the serpentine occurs are in places but a few feet wide, cutting an arkose similar to that in San Mateo and other Coast Range counties, where the rock is Cretaceous in age. They also cut some finer sediments. Other dikes are of diabasic character, and there is considerable glaucophane schist débris, though none was seen in place. The relations of the serpentine to the country rock are obscure, but it seems probable that the dikes are so faulted as to be locally discontinuous.

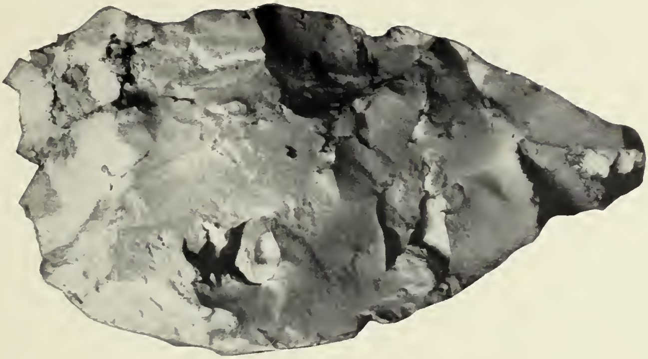
At the time this deposit was visited (November 29, 1906) work was being prosecuted by the Magnesite Products Company, of West Berkeley, Cal.

Magnesite veins, from 6 inches to a foot wide, outcrop on the surface at a number of places, but they show little continuity. At the main outcrop, which was close beside the road, a short tunnel cut a pocket of magnesite which was about 10 feet wide, 15 to 16 feet high, and 40 to 50 feet long. The serpentine is so faulted that if the mass ever continued onward it is now impossible to predict where the remainder may be found. About 500 tons was taken out and the workings abandoned.

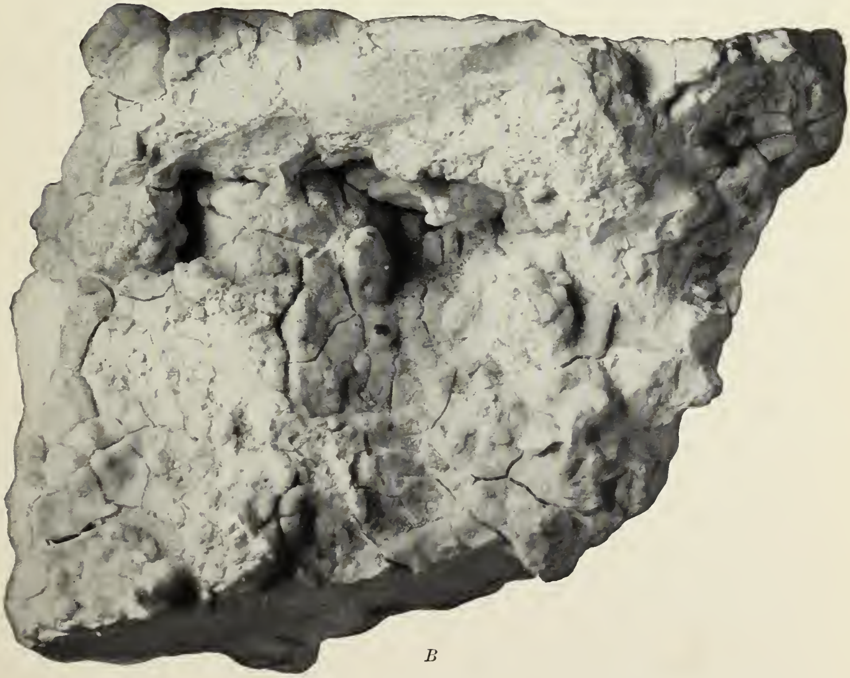
One-fourth mile N. 10° E. a vein 8 to 12 inches thick is exposed alongside the road, and half a mile east of the main workings a face of magnesite 9 feet high is exposed below the road. A tunnel 15 feet long had been driven into it, at the end of which the magnesite thinned and contained serpentine.

Besides these veins there were a number of smaller outcrops at other points in the neighborhood.

The magnesite in the worked deposit is but little discolored and portions are pure white, but all through it is scattered some serpentine only partially altered to magnesite. The mass has been much crushed and the pieces have been recemented by crystalline magnesite of a slightly greenish yellow color, which forms a layer



A



B

CRACKS IN MAGNESITE APPARENTLY DUE TO SHRINKAGE.

A, Compact magnesite from Hixon ranch, Mendocino County; *B*, Less compact magnesite coated with a thin layer of quartz, also cracked, from locality 4 miles northeast of Porterville.

about one thirty-second of an inch thick around the fragments. In places colorless fragile platy crystals coat the cavities. A partial analysis by A. J. Peters of a sample as nearly representative as could be selected gave the following results:

Partial analysis of magnesite from Creon deposit.

[Solution of air-dried material.]

Silica (SiO_2)	1.60
Alumina (Al_2O_3)	.25
Ferric oxide (Fe_2O_3)	1.09
Lime (CaO)	1.04
Magnesia (MgO)	45.20
Carbon dioxide (CO_2)	50.43
	99.61

No analysis was made of the magnesite from the other veins, which is less pure, part being yellow in color.

Eckert ranch deposits.—Three deposits of magnesite are said to occur on the Eckert ranch, on the edge of the valley 2 miles east of Cloverdale, but only two were seen by the writer. The more northerly is not more than 200 yards from the public road. Here on a soil-covered hillside a considerable amount of magnesite, roughly estimated at between 100 and 200 tons, has been excavated and piled up. The hole from which it was taken has been so filled with dirt that nothing could be seen of the rocks nor of magnesite left in place. The mineral is considerably stained, brownish and yellow, and gives the impression of being much more impure than it really is. Here too the magnesite is considerably cracked and the apertures are coated with a transparent crystalline magnesite, which at first glance looks like quartz.

A partial analysis by A. J. Peters is as follows:

Partial analysis of magnesite from north outcrop on the Eckert ranch.

[Solution of air-dried material.]

Silica (SiO_2)	0.51
Alumina (Al_2O_3)	1.98
Ferric oxide (Fe_2O_3)	.16
Lime (CaO)	.59
Magnesia (MgO)	45.84
Carbon dioxide (CO_2)	50.80
	99.88

In a plowed field, a quarter of a mile southeast of the occurrence just described, several rounded outcrops of magnesite, up to 4 or 5 feet across, occur in a line through a distance of about 75 feet. There has not been enough excavation to show whether they belong to one vein or whether they are merely nodules of large size. No relationship between these outcrops and the northern deposit can be traced.

The magnesite is much whiter and purer than that in the northern deposit, and is nearly free from lime. A partial analysis by A. J. Peters is as follows:

Partial analysis of magnesite from southern outcrop on Eckert ranch.

Silica (SiO_2)	0.23
Alumina (Al_2O_3)	.04
Ferric oxide (Fe_2O_3)	.20
Lime (CaO)	.19
Magnesia (MgO)	46.88
Carbon dioxide (CO_2)	51.57
	99.11

George Hall ranch deposit.—About 3 miles southeast of Cloverdale, on the George Hall ranch, in the south bank of a deep ravine running toward Russian River, there is a small outcrop of magnesite about 20 feet above the bed of the stream. Although the magnesite is white and appears to be of good quality the outcrop is only 4 or 5 feet broad in greatest dimension, so that it gives little promise of value.

Pat Cummings claim.—The Pat Cummings deposits are in a serpentine hill 2½ or 3 miles S. 35° W. (magnetic) from Cloverdale, at a height of about 1,200 feet (barometric) above that town. At the northernmost occurrence a few tons of magnesite has been mined and thrown out, but none can be seen in place. The magnesite is white, but like that in most of the other deposits has been much brecciated. The cracks between the fragments, however, instead of being coated with crystalline magnesite as is usually the case, are lined with clear colorless chalcedony, so that the percentage of silica present is large.

About one-fourth of a mile farther south are two outcrops of impure magnesite 8 to 12 feet in diameter.

Gilliam Creek deposits.—In the northwest corner of sec. 6, T. 8 N., R. 10 W., Mount Diablo base and meridian, on the steep western side of Gilliam Creek, 400 or 500 feet above the stream and about 7 miles northwest of Guerneville, are a number of large outcropping veins of magnesite. They occur in a space about 300 feet long, following the creek, and about 100 feet wide, measured along the slope. The country rock is as usual a serpentinized basic rock. The veins stand out boldly; one near the southern side of the claim is 6 to 8 feet thick and rises more than 20 feet above the hillside. Great masses of magnesite have fallen from the outcrop and lie on the surface or are partly buried in the débris. There are many smaller veins and probably one or two as thick as that from which the outcropping portions have broken, so that, as float or outcrop, several thousand tons of magnesite in large pieces are in sight. Other veins undoubtedly occur north of this deposit, as there are many bowlders of magnesite in the creek. Smaller deposits are said to occur down the creek (south) from the main outcrops. Except the deposits at Red Mountain, these are from surface indications the most extensive seen by the writer in California. The magnesite here, however, contains a greater amount of impurities than that at Red Mountain. (Compare analyses on p. 36.)

A partial analysis, made by A. J. Peters, of a sample picked to be as nearly representative as possible, was as follows:

Analysis of magnesite from west side of Gilliam Creek.

Silica (SiO_2)	3.51
Alumina (Al_2O_3)	1.10
Ferric oxide (Fe_2O_3)	.80
Lime (CaO)	1.46
Magnesia (MgO)	43.65
Carbon dioxide (CO_2)	49.16
	99.68

This magnesite is probably too impure for use as a material for cement, but should make brick which would compare well with the Austrian, and is good for gas and wood-pulp bleaching.

The property is owned by the Western Carbonic Acid Gas Company. About a mile of new road was necessary to connect the deposit with an established highway, and this was being constructed at the time of the writer's visit (December 3, 1906). No magnesite had then been shipped from the deposit.

Madeira deposit.[a]—The Madeira deposit was unknown to the writer at the time of his trip into Sonoma County, and so was not visited. It is in sec. 31, T. 9 N., R. 10 W., which adjoins on the north the section in which is located the Western Carbonic Acid Gas Company's claim, and is said to be a rather extensive deposit of magnesite containing considerable silica. The best exposures are said to be along a small tributary of Gilliam Creek. It will be necessary to build between 1 and 2 miles of wagon road before the magnesite can be hauled to the railroad.

Unnamed deposits.—About three-fourths of a mile northwest of the Western Carbonic Acid Gas Company's deposit, probably in sec. 36, T. 9 N., R. 11 W., near the top of a high hill, are a number of magnesite veins from 2 to 10 inches or more in thickness. One vein about 10 inches thick is exposed broadside along the face of a bluff perhaps 30 feet high. The quality of the magnesite here is apparently very good, though a number of the veins contain much serpentine. At one place there is a reticulated vein whose individual members are from 4 to 8 inches thick. This vein, which was formerly made up of

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[a] Data furnished by Chester Naramore.

opaque white magnesite containing some serpentine, has been much broken. Around the fragments light-green, radially crystallized magnesite has formed, and cavities that still remained have been filled with milky chalcedony. The mass now consists largely of the green crystalline magnesite and is striking in appearance. It is said that at one time an attempt was made to work the deposit for ornamental stone, under the impression that it was Mexican onyx (onyx marble). There are too many imperfections in the material to make it desirable for this use. An old road, now fallen into bad repair, leads past the deposit to another road running to Healdsburg, which is about 11 miles distant. Should it become desirable to work these veins, the railroad could probably be reached more easily at Healdsburg than at Guerneville. Magnesite float was seen in a number of creeks in the neighborhood, showing the existence of other deposits, whose extent is unknown.

Red Slide deposits.—The Red Slide deposits are situated near a natural feature known by that name in the valley of East Austin Creek, in T. 9 N., R. 11 W., about 8½ miles by road north of Cazadero. The serpentine on the high hill in which the deposits are situated is stained with iron oxide, and there is so much slipping of the rock that vegetation can not exist on that portion of the hill, whence the name "Red Slide." It may be seen from other hilltops for long distances and so is a familiar landmark.

A large belt of serpentine, whose limits are unknown, runs through this portion of the country, and in it occur the magnesite deposits. In the group examined, which lies on the west side of the creek, there are several outcrops up to 5 and 6 feet wide and a number of smaller ones.

At the time the deposits were visited (December 4, 1906) the Sonoma Magnesite Company was doing development work on them. Two tunnels had been run into the hill, one a few feet above the creek and the other about 80 feet higher up the hill and 100 feet or so upstream.

The upper tunnel was well driven, 93 feet long, 6 feet high, and 7 feet wide. Three veins 5 to 6 feet thick and a number of smaller ones had been cut. There was but little work to show the extent of the veins beyond their thickness and they could not be followed on the surface. Much more development work is said to have been done since then. At one point magnesite was said by Mr. E. W. Arnold, the superintendent, to have formed during the preceding winter, and it gave much evidence of being a recent deposit. Water trickled over a face of magnesite exposed by mining, and a soft nodular deposit, somewhat resembling a spring deposit of calcite, covered that portion of the wall. Owing to the fact that shrinkage cracks are frequently found in magnesite, the question arose in the writer's mind as to whether magnesite was not deposited as a hydrous carbonate, and a specimen of the material was collected and later tested in the Geological Survey chemical laboratory, where it was pronounced anhydrous. Evidence of considerable faulting appears in the upper tunnel and small veins show dislocations of a foot or less. One of the larger veins was followed for but a few feet before it gave out.

The lower level was 200 feet long and of the same cross section as the upper one. It started in on a vein of magnesite which appeared to be about 9 feet wide (Pl. V, *B*), but the entrance is not at right angles to the vein, and the magnesite on the right side of the vein grades into serpentine. There is probably not more than 6 feet of clear magnesite. The tunnel did not follow this vein far and only one other was cut. This second vein has been faulted, and though apparently about 6 feet wide, but little could be told of its extent. The attempt to crosscut the veins cut in the upper tunnel was unsuccessful. It seems altogether likely that the general remarks about the indefinite extension of magnesite veins in any direction will apply with full force here. These veins will probably be found to be of much less length and depth than might be expected from their width, if they were to be judged by the ordinary characteristics of quartz veins.

The magnesite is of a creamy color and contains considerable silica. It is, however, remarkably free from lime. A partial analysis, by A. J. Peters, of a sample selected to represent as nearly as possible the average rock gave the result stated below. There is no doubt that better or worse specimens might be taken.

Analysis of magnesite from Red Slide deposits.

Silica (SiO_2)	7.67
Alumina (Al_2O_3)	.26
Ferric oxide (Fe_2O_3)	.29
Lime (CaO)	.04
Magnesia (MgO)	43.42
Carbon dioxide (CO_2)	48.08
	99.76

A large quantity of magnesite, estimated by Mr. Arnold to be almost 2,000 tons, though this figure seemed somewhat large to the writer, lies on the dumps. There is also a good deal of float magnesite in the creek. The road from the workings to Cazadero crosses a mountain with grades so steep that it is impossible to haul the magnesite out at a profit. The road to Guerneville is as bad, or worse, and longer, so that at present the magnesite can not be marketed. Should a way to haul the rock out be obtained, the company expects to make artificial stone and tiles. The company claims to have a much better deposit 2½ miles farther up the creek, where a vein is said to be from 10 to 25 feet thick and to have been followed for 900 feet.

Norton ranch deposits.[a]—On the Ed. Norton ranch, along Dry Creek, 10 miles northwest of Healdsburg, is a deposit of rather siliceous magnesite in large rounded chunks lying upon serpentine and overlain by clay and black soil. There is no outcrop, and the magnesite is exposed only by trenches.

NAPA COUNTY.

General remarks.—Like all the other counties along the Coast Range, Napa County has a rough topography, so that railroad and wagon-road building over most of it is difficult. The beautiful Napa Valley, from 1 to 4 miles wide, runs the whole length of the western side of the county, and east of it, separated by rough hills, lie Chiles and Pope valleys, of much less extent. Only in the Napa Valley is there a railroad, though projects for an electric road to traverse both of the other valleys on its way to Lake County have been agitated for many years. At one time grading was done over a part of the route, and later another company constructed a road for a portion of the distance through the Napa Valley.

All the known deposits in this county are situated east of the Napa Valley, with rather long and, in some cases, difficult hauls to the railroad. Rutherford is the most easily reached station and the road through Conn Canyon is the first stretch of the route to any of the deposits.

Walters or White Rock deposit.—The deposit bearing this name is located in the NE. ¼ sec. 11, T. 9 N., R. 5 W., on the east side of Pope Valley, 22 miles northeast of Rutherford. The distance from the railroad makes hauling expensive, and the claim, which was never worked on a large scale, has made no production for several years. The proposed electric road from San Francisco to Lake County, if built, will pass within 4 miles or less of the deposit, and the claim will then be in an excellent position to ship magnesite.

The deposit is situated about three-fourths of a mile from a public road in a hill of serpentinized lherzolite, about 400 feet (barometric measurement) above the valley. It is composed of a large number of veins whose exposures range in width from a fraction of an inch to 12 feet and lies on both sides of a small ravine that forms an amphitheater, with an easy, straight southward grade to the valley, making an almost ideal place to work with an aerial tram.

The veins are in three principal groups, two of which lie on the east side of the ravine and the other on the west. The main group on the east side comprises three large veins of magnesite that can be definitely traced for distances of about 140, 250, and 230 feet, with strikes of N. 28°, 30°, and 45° W., respectively. At their north ends the western and eastern veins are but 30 feet apart, and the middle

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[a] Description furnished by Chester Naramore.

vein probably converges with the eastern one. A shallow shaft on the western vein shows its dip to be 50° N. 62° E. The veins stand out boldly and can be seen from any part of the valley not hidden by hills. (See Pl. V, *C.*) Longitudinal faults occur in both of the outer veins. Between the large veins are many smaller ones having a general parallelism to the main bodies. At its widest exposure the western vein is about 10 feet thick, of which about 5 feet on the foot wall is solid white magnesite, although the upper 5 feet on the hanging-wall side contains many inclusions of serpentine. The structure of the eastern vein is similar, and in places the magnesite may be seen grading into the country rock; it is about 12 feet wide where exposed in a shallow crosscut. In the middle vein a width of 18 inches to 5 feet of clear white magnesite is exposed. There has been some crushing of the magnesite and the broken particles have been cemented with yellowish, less pure material. Part of the magnesite has formed in yellowish botryoidal masses that are rather impure. Some crystalline magnesite, similar to that of Chiles Valley, is found in the crevices. It is said that 1,250 tons was mined between 1894 and 1899, being simply broken from the exposed faces of the veins.

A second group with a more northerly strike lies 100 feet or more above the veins just described. The veins forming this group are smaller, running from 2 inches to 2 feet in width, and the larger of these are impure. There are also many scattered veins in the intervening space.

On the west side of the ravine, 200 to 250 feet from the veins first described, is a third group with a strike between north and northwest. The largest vein is 4 to 6 feet wide; and seven others from 1 to 2 feet wide occur within 125 feet. All appear to be of excellent quality. It would seem possible to blast out the whole of the rock through this distance and hand-pick it at a profit should the deposits again be worked. A prospect tunnel was run into the hill near these veins and struck an irregular vein of crushed magnesite at the end.

Snowflake and Blanco claims.—Magnesite was mined by Bartlett & Stanley at a place about 2 miles south of the old Chiles mill, in Chiles Valley, and 10 miles from Rutherford, for a number of years, but the mine has not been operated since 1900, as it is too far from the railroad to compete with points having better shipping facilities.

Here also the country rock is the serpentine of the Coast Range, inclined to a dark-green or blue-black color. The deposits are on the west side of the valley, in a small serpentine hill skirted by a public road, and consist of a number of veins which range in thickness from 1 foot to 6 feet and are said to have been as much as 12 feet wide. Where seen, however, the larger veins were considerably mixed with serpentine and other impurities. Marked faulting occurs with the veins, and both the hanging and foot walls are generally fault planes. The serpentine is much broken and greatly decomposed in the neighborhood of the veins, the interstices being filled by smaller veins of magnesite.

On the foot walls of several of the veins extensive silicification has taken place, the serpentine being hardened through 2 or 3 feet. The veins are locally brecciated and cemented with less pure material of yellowish color, the original magnesite being a clear white. At many places in the brecciated portions each fragment is covered by magnesite in radial crystals, forming a coating up to half an inch thick and varying in color from crystalline clearness to delicate green and yellowish green. Cracks in the serpentine are also filled with the same crystalline magnesite. This material is strikingly different from the ordinary magnesite, which shows no crystal form to the unaided eye. In places crevices in the veins have a velvety black coating of pyrolusite (manganese dioxide), making the rock look as if it were coated with lampblack. A small amount of chromite has been found in the neighborhood, but not in paying quantities. Partial analyses of magnesite from this mine are given below:

Partial analyses of magnesite from the Bartlett & Stanley mine, Chiles Valley.

	1.	2.	3.
Silica (SiO_2)	2.15	1.81	6.68
Alumina (Al_2O_3)	1.22	.08	15.10
Ferric oxide (Fe_2O_3)	1.16		
Lime (CaO)	5.28	Trace.	....
Magnesia (MgO)	41.01	46.55	37.23
Carbon dioxide (CO_2)	48.72	51.25	40.98
Water and undetermined	....	.32	....
	99.54	100.00	99.99

Analysts: No. 1, P. H. Bates, United States Geological Survey; Nos. 2 and 3, Abbott A. Hanks, San Francisco, October 1, 1903.

Specimen No. 1 was collected by the writer and was as nearly representative as was possible to select; No. 2 was probably a picked sample, and No. 3 was of a poor quality, not shipped. The lime content of the first specimen is very high.

During the time that the mine was worked probably 10,000 to 12,000 tons of magnesite was taken out and calcined. As pure magnesite loses more than half its weight by being calcined, a large saving was made in haulage by getting rid of the carbon dioxide when the material was to be used as magnesia. A four-sided shaft furnace, built of serpentine and sandstone blocks and lined with firebrick, was used. It was about 15 feet high and from 3 to 5 feet across. The furnace was fired from the four sides at the base of the shaft, largely with manzanita, a hard-wooded shrub making a hot fire, and the calcined magnesite was withdrawn from below. The waste magnesite fines below the furnace have compacted noticeably from recarbonation.

Priest deposit.[a]—D. C. Priest has a magnesite deposit in Chiles Valley, in sec. 23, T. 8 N., R. 4 W., about 13 miles from Rutherford. One 2-foot and one 18-inch vein are exposed, well up a hillside, and magnesite of a rather poor quality is exposed in a lower opening. No work has been done on the deposit for a number of years.

Russell deposit.[a]—E. T. Russell holds a claim in sec. 24, T. 8 N., R. 4 W., on which several small magnesite veins outcrop. About 25 tons was shipped at one time. The deposit is 4 miles from a road and 15 miles from Rutherford.

Matthai deposits.[a]—Frank Matthai formerly held a claim known as the "North mine" in Soda Creek canyon, in the NE. ¼ sec. 35, T. 8 N., R. 4 W., near the public road. Irregular veins and masses of magnesite several feet thick outcrop in serpentine on this claim. Bartlett & Stanley mined the larger masses by open cuts in 1895, but the property has been idle since. Much magnesite still remains in sight.

The "South mine," also held by Mr. Matthai, lies a quarter of a mile southeast of the "North mine," on the other side of a low ridge, on the north bank of Greasy Camp Creek. A 5-foot vein of clear white magnesite outcrops along the creek for about 30 feet, dipping into the hill at a low angle. At the time the mine was visited (1905) two open cuts and a short tunnel had been made, and about 100 tons of magnesite was piled up.

SANTA CLARA COUNTY.

Deposit near Coyote.—A small deposit of magnesite occurs on W. W. Burnett's ranch, about 3 miles northeast of the Coyote railroad station and half a mile north of the summit of the Metcalf road. The deposit occurs near the top of the east slope of a hill several hundred feet high in a belt of impure serpentine, which weathers in rough, irregular forms. The exposed portion of the vein is about 100 feet in length and 4 to 10 feet wide, striking N. 35° W. (magnetic), apparently with a nearly vertical dip. A ravine cuts off the vein on the south, but some pebbles of magnesite were found on the south side, so that there may be on that side either another deposit or an extension of this one. The main part of the vein is of good quality, but a part of the magnesite is rather siliceous and contains fragments of serpentine now almost entirely replaced by silica and magnesite. The fragments on the surface south of the ravine are still more impure.

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[a] Data furnished by Chester Naramore.

A partial analysis by A. J. Peters of a specimen from the large vein gave the following result:

Partial analysis of magnesite from W. W. Burnett's ranch, Coyote.

Silica (SiO_2)	0.30
Alumina (Al_2O_3)	.16
Ferric oxide (Fe_2O_3)	.38
Lime (CaO)	1.34
Magnesia (MgO)	45.86
Carbon dioxide (CO_2)	51.80
	99.74

The magnesite seems to be suitable for brick, gas making, and paper making, but probably has too much lime to make good oxychloride cement.

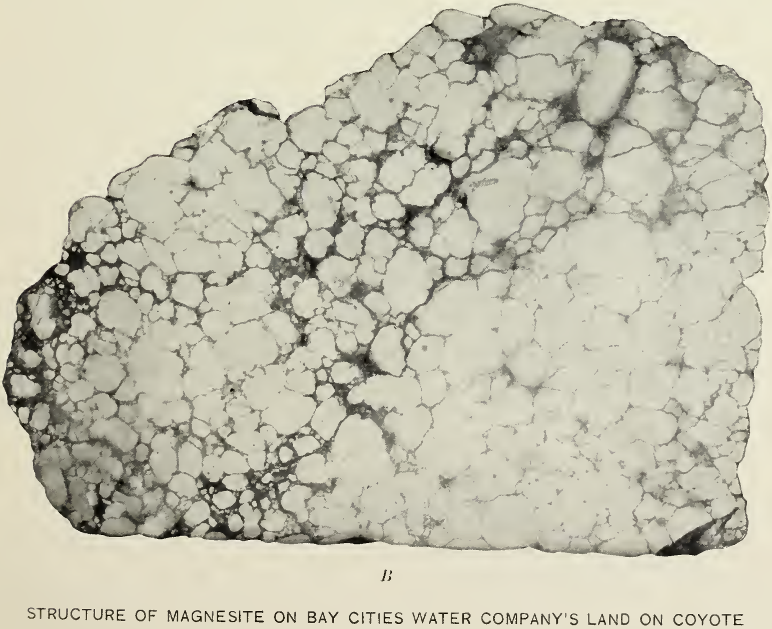
As is usually the case, the serpentine is much more decayed near the vein than in other places. On the west wall of the vein the serpentine is so much impregnated with magnesite that it has a gray appearance for a thickness of several feet. In other places it has a glassy aspect over small areas, but the quantity is too small and the serpentine is too much cracked to permit its utilization as an ornamental stone. Many small veins of cryptocrystalline quartz cut the serpentine in various directions. In some of the veins are small vugs showing crystallized quartz.

Bay Cities Water Company's land.—A couple of miles northeast of Morgan Hill station Coyote Creek turns abruptly to the west from a northward course and flows through a serpentine ridge into the Santa Clara Valley by way of a narrow cut, on the north side of which are several veins of magnesite. The serpentine in which they occur is similar to that east of Coyote station, and may be a part of the same dike. The lowest vein is perhaps 250 yards west of San Felipe Creek, which joins Coyote Creek at its westward bend. The outcrop of the vein strikes N. 85° E., is about 10 feet wide and 50 feet long, and forms the point of a small hill.

The magnesite is made up of rounded irregular particles ranging from half an inch downward in diameter (see Pl. VII, *B*), cemented by siliceous magnesite, which for an inch or more from the surface is stained red by iron. Many chunks of iron-stained quartz 2 feet or more in diameter lie on the ground near the outcrop. No work has been done on this vein.

About 100 feet farther up the hill is a larger deposit of rather impure magnesite, which does not carry so much silica, but has much serpentine mixed through it. A number of extremely irregular veins interlace through an area 200 feet long by 50 to 100 feet wide. In places the magnesite has an oolitic structure, analogous to the structure of the vein lower down the hill, but the particles are all small,

A



B

STRUCTURE OF MAGNESITE ON BAY CITIES WATER COMPANY'S LAND ON COYOTE CREEK.

A, Specimen from the upper deposit, showing a natural surface; *B*, Specimen from the lower deposit, showing a smoothly ground surface. Both natural size.

only a few grains reaching one-eighth inch in longer diameter. (See Pl. VII, *A*.) At the outer part the fragments are separated by talcose matter, but the mass becomes gradually more compact until the particles coalesce and form dense, solid magnesite. The principal vein runs almost parallel with the course of the hill, and a face 10 to 20 feet high has been exposed by a cut. In places segregations of clear-white magnesite reach 2 to 3 feet in thickness, but other portions of the vein are but a few inches thick. The material could be hand picked and a fair to good quality obtained.

An old sheet-iron furnace is in ruins on the ground, and it is said that an attempt was made to calcine the magnesite some years ago. Several carloads of the raw material are reported to have been shipped.

Mrs. A. F. Cochrane's land.—About 1½ miles south of the junction of Coyote and San Felipe creeks and about 3½ miles from Morgan Hill station, on the land of Mrs. A. F. Cochrane, is a rather bold outcrop, several feet wide, of a fine-grained buff-colored magnesite, which can be followed for more than 200 feet up the hill.

The serpentine shows much silicification and iron staining. In places blocks 8 or 10 feet thick are almost wholly replaced by iron-stained quartz. Elsewhere the cracks in the serpentine have been filled with quartz, very much as at other deposits the cracks have been filled with magnesite. The serpentine between the quartz veins is much decayed and in places drops out, leaving an irregular skeleton of silica much stained with yellow and red iron oxides. The great amount of iron present in this locality is very noticeable, and to it the magnesite probably owes its buff color, although the analysis shows but 0.18 per cent of ferric oxide. Silica makes nearly half of the rock. A partial analysis by A. J. Peters is as follows:

Partial analysis of magnesite from Mrs. A. F. Cochrane's land, near Morgan Hill.

[Solution of air-dried material.]

Silica (SiO_2)	49.85
Alumina (Al_2O_3)	3.45
Ferric oxide (Fe_2O_3)	.18
Lime (CaO)	.48
Magnesia (MgO)	21.53
Carbon dioxide (CO_2)	23.96
	99.45

In places small fragments of dull-yellow magnesite are included in the quartz. It is reported that some work was done on the deposit in 1897 and that several carloads of magnesite were shipped to San Francisco.

Red Mountain deposits.—Near Livermore, a town 48 miles southeast of San Francisco, there are a number of magnesite deposits, of which the only one now being worked is that of the American Magnesite Company, 32 miles southeast of Livermore on Red Mountain, in the northeast corner of Santa Clara County, along the Stanislaus County line. A number of the company's claims are located in the latter county. From Livermore an excellent road follows up the Arroyo Mocho, crossing into and running down the Arroyo Colorado. The maximum grade for the haul from the mine is said to be 3 per cent. At the mines the company has erected good buildings and roads, and an aerial tram 2,500 feet long, with a capacity of 100 tons per ten-hour day, delivers the magnesite to bunkers, from which it is loaded into wagons for hauling to Livermore. An attempt was made to haul the magnesite with oil-burning traction engines drawing two iron wagons carrying 17½ tons each, and two such trains were put into operation, but are reported to have been unsuccessful. The haul to the railroad is very long for a product of no greater value than magnesite, and can scarcely be profitable. The magnesite is shipped to Oakland, where the company's factories for brick, carbon dioxide, and other products are situated. The mine offices and other buildings are located near springs that give sufficient water for the engines, the mine, and other purposes. The country rock is lherzolite and peridotite, in some places much serpentinized and in others remarkably fresh. The magnesite occurs in the more altered portions.

Although these deposits have been known for a long time, they were not worked until 1905, owing to their distance from a railroad. They occur in a number of veins in a group around a small valley, so arranged as to be excellently located for working by adits and an aerial tram. Just how many veins there are can not be stated, as the brief time at the writer's disposal did not allow examination of the smaller ones. Owing to débris and faulting it is not possible to tell whether many of the outcrops belong to the same veins as neighboring ones or whether they are separate deposits. In the immediate vicinity there are, however, probably 10 or 12 veins, and possibly more, 2 feet or over in thickness, all of which could be well worked with but slight changes in the plant installed.

The veins stand out prominently in the bright sunshine of the valley and are almost dazzlingly white, so that they can be seen from the higher hills miles away. One of the veins, called the "Mammoth," stands fully 10 feet above the hillside.

The magnesite shows a number of peculiarities in weathering. Some of the surfaces weather into a pattern that looks like sun cracks in mud (see Pl. IV, *B*), with flatly oval surfaces from one-eighth to three-fourths of an inch wide between the cracks. In places there are fluted surfaces, such as occur on exposed limestones, but in narrower lines (see Pl. III, *A*), and locally the weathered surface is thickly studded with sharp points. Many exposed surfaces are covered with a white powder which has been supposed to be magnesium oxide or hydromagnesite, but which has been determined to be another form of magnesite. Underground also nodules or portions of veins of magnesite in places have turned to this powder, leaving a core of solid material. Mr. C. H. Spinks, the superintendent of the mines, told the writer that certain other veins a few miles distant, belonging to the company, carried very much more of this powder. Powdery magnesite has been described as occurring also in South Africa. (See p. 60.) Why it should take this form, breaking down from the solid state without apparent chemical change, is unknown.

Only one vein on the Alameda claim, near the top of the ridge, was being worked in November, 1905, when the claims were visited, and the first magnesite was shipped in that month. This vein has a strike of N. 30° W. (magnetic), with a steep southwesterly dip. It ranges in thickness from 15 to 40 feet, and could be definitely followed for about 300 feet S. 30° E. from faults against which it ends at the north. Whether the vein has been faulted off or whether its termination was originally fixed by the fault was not clear. Although the fault mud and breccia contains some crushed magnesite, this may come from other sources. Veins of rosiny opal and an aluminous siliceous material, 1 inch to 3 feet thick, occur along the fault. The magnesite is also badly cut and crushed by faults and contains in places much serpentine and some of the aluminous siliceous veins.

On approaching the vein through the tunnel one sees that the serpentine is greatly decayed and is cut in every direction by innumerable small veins of magnesite, crossing each other at all angles. Here and there, in veins which do not exceed 2 or 3 inches in thickness, sudden enlargements occur, which may be 3 feet in diameter and almost equidimensional. These are referred to as "bowlders," but they have nothing in common with bowlders beyond size and shape. Some of the smaller nodules are partly composed, mostly in the outer portion, of aluminous and siliceous material, the inner portion appearing to be comparatively pure magnesite. This material seems to be a replacement of the magnesite similar to the replacement of calcite by silica. The small veins grow in number and in thickness until by steady gradation the mass of comparatively pure magnesite is reached. At other points the vein's walls are abrupt and are probably delimited by faults. The vein was pierced by several adits on different levels, and a crosscut at one place entered the vein for 35 feet without going through it. A drill hole 8 feet long at the end of the crosscut was said not to have reached the other side. The magnesite is pure white, the crosscut looking as if freshly whitewashed. As is to be expected in a serpentine area, faults have cut the vein in a number of places, and through at least a portion of their length both hanging and foot walls are fault planes.

At several places pipes or nearly vertical channels, 6 inches and upward in diameter, now largely filled with clay, have been cut through the magnesite by water. The walls of these channels are much smoother than those of most similar channels cut in limestone, owing probably to the homogeneous composition of the magnesite. At two places the watercourses were large enough to use as chutes.

Mining is carried on by means of an open cut, in which the magnesite is quarried and allowed to fall through an upraise to an adit below, whence it is moved in cars to the aerial tram. The tramway drops 600 feet in the 2,500 feet to the bunkers. The skips are placed 500 feet apart and each carries 1,000 pounds of magnesite.

On the Canada claim, several hundred feet down the hill from the worked vein, is a large irregular outcrop of magnesite, between 40 and 50 feet across, which had not been prospected at the time the claim was visited. Later it was reported that a prospect tunnel run under this outcrop had shown the magnesite to contain much included serpentine.

Just across the ridge from the point at which mining was being carried on is the outcrop of the "Mammoth" vein, already referred to, which stands more than 10 feet above the hill slope on its lower side. It is about 4 feet thick and apparently is of excellent quality. It had not been prospected, so that nothing could be told of it beyond its outcrop.

A number of other veins in the group are up to 10 feet wide and at least one can be followed for 200 yards. They are not all equally pure, and several contain a considerable amount of included serpentine.

Extravagant estimates of the amount of magnesite in sight have been made, but though the amount exposed is large, the development at the time the deposits were visited was not extensive, and from the outcrops alone but two dimensions can be known, so that estimates of the total amount available are but little better than guesswork. Ravines cutting across the strike of the veins do not expose them and show that they are continuous for long distances.

The following are partial analyses of magnesite from the Alameda claim:

Partial analyses of magnesite from Alameda claim, Santa Clara County.

	1.	2.
Silica (SiO_2)	0.73	3.93
Alumina (Al_2O_3)	.14	.20
Ferric oxide (Fe_2O_3)	.21	
Lime (CaO)	.40	1.16
Magnesia (MgO)	46.61	....
Carbon dioxide (CO_2)	51.52	....
	99.61	5.29

Analysis No. 1 was made by A. J. Peters, of the United States Geological Survey. No. 2 was made by E. T. Allen, of the Carnegie Institution geophysical laboratory, to determine the amount of impurities present, preparatory to using the magnesite in his experimental work. Both specimens were collected by the writer, and the second was picked out for its whiteness under the supposition that it would be especially pure. F. E. Wright determined microscopically that the silica was present as quartz, and not as combined silica.

Close to the magnesite veins, about 250 yards southeast of the present workings, are small impregnation veins of chromite. The chromite occurs in grains from the size of a pea downward, and can be clearly seen to spread from joints in a serpentinized peridotite. It is accompanied by a pale lilac-colored chlorite, probably either kotschubeite or kammererite. A small amount of work has been done on the veins, but the prospects do not seem to have been encouraging. A little cinnabar is said to have been found in the neighborhood, and two mercury mines are being developed within a radius of 4 or 5 miles.

On Cedar Mountain, in Alameda County, the company had also located eight magnesite claims which, however, were not being worked and were not visited.

Other Santa Clara County deposits.—There were said to be other deposits in the neighborhood of Coyote, but the locations given were so indefinite that they could not be found. Small deposits are said to occur in Alum Rock Park, near San Jose, and in the vicinity of the mercury mines at New Almaden, but they are without commercial importance. From the amount of serpentine in the county it is rather to be expected that there should be other occurrences of magnesite.

ALAMEDA COUNTY.[a]

King claim.—Two miles from the Arroyo Mocho road and 22 miles southeast of Livermore, on the King claim, several small veins of magnesite are exposed in a cut. There has been no production.

Banta's camp deposit.—In sec. 16, T. 5 S., R. 4 E., on a narrow ridge southwest of Banta's cabin in the Arroyo Mocho canyon, 24 miles southeast of Livermore, is a small outcrop of magnesite. There has been no development.

STANISLAUS COUNTY.

Some of the American Magnesite Company's deposits (see p. 34) are in Stanislaus County, adjoining the Santa Clara County line. It is probable that other deposits occur along the western edge of the county, where the brushy, sterile hills of the serpentine area are but seldom traversed.

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[a] Data furnished by Chester Naramore.

SAN BENITO COUNTY.

Extensive areas of serpentine occur in San Benito County, in which are located the New Idria mercury mines, now the largest producers in California. No magnesite has been reported, but it is probable that it may yet be found. At present transportation facilities are poor, and in wet weather the roads are very bad.

SAN LUIS OBISPO COUNTY.

Magnesite in small veins is reported to occur on the Kiser place, 8 to 9 miles northwest of Cambria. The country is rough and the deposits are a long way from railroad transportation. San Simeon, a port of call for coastwise vessels, is the nearest shipping point.

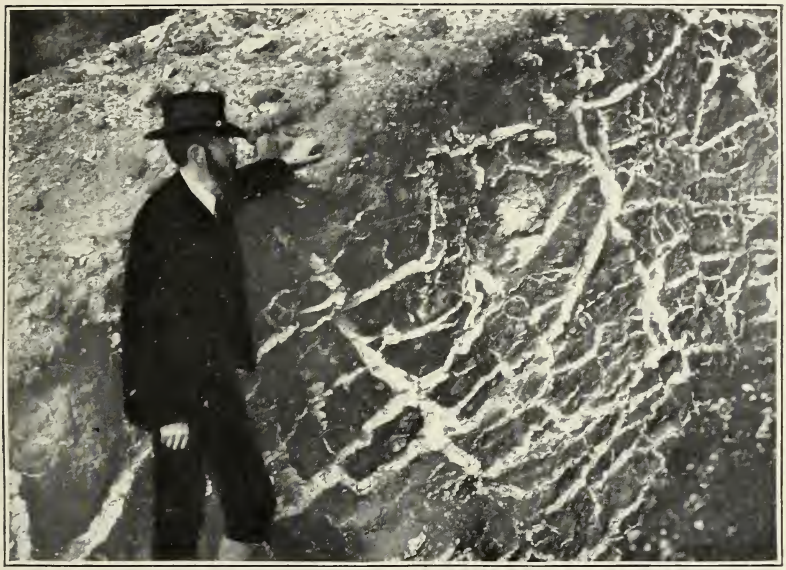
SANTA BARBARA COUNTY.

Specimens of magnesite seen at Santa Barbara were said to come from a deposit about 20 miles back in the mountains. No details could be obtained, but the specimens seemed to indicate that they had come from rather small veins. As a guide could not be obtained and there were no trails, the deposit was not visited.

RIVERSIDE COUNTY.

About 3½ miles south of Winchester, in a hill rising about 650 feet above the surrounding valley, intrusives, now changed largely to serpentine, have been thrust into biotite schist standing on edge and having a general northwesterly strike. The limits of the serpentinous bodies are rather vague, but the masses are probably several hundred feet thick. Pegmatite dikes, carrying tourmaline, cut both schist and serpentine. The dikes range in thickness from 4 inches to a number of feet, and where they cut the serpentine chlorite is developed for a distance of 2 to 6 inches on each side. At several places along the schist-serpentine contact radial asbestos of a poor quality has been formed through a thickness of 6 to 8 feet. Narrow veins of fibrous asbestos are developed along a vein of magnesite a few inches thick in a tunnel about 70 feet long, which was run into the hill in search of gold.

At a number of places in the serpentine trenches have been dug exposing magnesite stockworks with veins ranging in thickness from 2½ inches down to those too small to be readily noticeable. (See Pl. VIII, *A*.) From the best exposure, near the top of the hill, a piece of magnesite 6 inches thick, 18 inches wide, and 3 feet long was said to have been taken out, and was the largest piece found. In general the veins at this point are from one-half inch to 2 inches thick, with local enlargements. The distance between veins ranges from 3 to 10 inches. The magnesite itself is spongy and porous.



A. STOCKWORK OF MAGNESITE VEINS 3½ MILES SOUTH OF WINCHESTER.

B. SHEETED SERPENTINE CONTAINING THIN VEINS OF MAGNESITE, NEAR DEER CREEK, TULARE COUNTY.

A partial analysis of the magnesite by P. H. Bates, of the United States Geological Survey, is as follows:

Partial analysis of magnesite from hill near Winchester.

Silica (SiO_2)	4.73
Alumina (Al_2O_3)	.12
Ferric oxide (Fe_2O_3)	.08
Lime (CaO)	.43
Magnesia (MgO)	44.77
Carbon dioxide (CO_2)	49.40
	99.53

The lime is fairly low and there is little iron, but the silica is high. A company has been formed to work the magnesite, but that these deposits can compete with larger ones turning out as good or better rock in other parts of the State seems doubtful.

In a well bored in the valley about a mile northwest of this deposit a magnesite vein 20 inches thick is said to have been struck. It was supposed by some that there must be a connection between this vein and the other deposits, but there is no ground for this belief, and such a connection is altogether unlikely.

THE SIERRA NEVADA OCCURRENCES.

KERN COUNTY.

Magnesite is said to exist in Walkers Pass, in the Sierra Nevada, east of Bakersfield, but the deposits are so far from railway transportation that they are not now of economic importance. A specimen seen at Bakersfield was solid and of good white color.

TULARE COUNTY.

White River deposits.—Veins reaching 6 inches in thickness are reported to occur along White River, 4 or 5 miles west of Tailholt, but none of workable size are known.

Deer Creek deposits.—On and near the top of a serpentine hill about 1 mile south of the schoolhouse at Simmon's ranch, about 8 miles southeast of Porterville, there are a great number of comparatively thin veins of magnesite. The hill is a portion of the outside range of foothills, in front of which lie two or three smaller hills, also of serpentinized rock. In one, directly in front of the magnesite deposits and about 1 mile west, chrysoprase veins are being mined. A similar occurrence of chrysoprase veins in serpentine containing magnesite has been noted at Frankenstein, Silesia.[a] Veins of chalcedony up to 3 inches thick, showing greenish tints, occur near the magnesite veins. The country rock is a dull brown serpentinized peridotite

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[a] Squire, Lovell, Some observations on the magnesite of Silesia: Trans. Royal Geol. Soc. Cornwall, vol. 9, pt. 1, 1875, pp. 59-70.

similar to that near Porterville. (See below.) As in the Porterville area, the rock is sheeted in places and contains great numbers of perpendicular thin parallel veins of magnesite, not over an inch thick and about an inch apart. Crossing the perpendicular veins at a small angle are a second series of veins, and a third series crosses at right angles. (See Pl. VIII, *B*.) The veins are probably due to shearing, which produced cracks. These cracks then formed channels for surface waters, and were filled by magnesite derived from the decomposition of the inclosing rock and brought by the waters from a distance and precipitated. Some, but not many, of these veins reach 2 feet in thickness for short distances; generally they are discontinuous and irregular.

A small amount of magnesite of excellent quality has been mined on the west side of the hill from a nearly vertical vein running parallel to the course of the hill and ranging from 10 to 18 inches in thickness.

A specimen obtained on the top of the hill was partly analyzed by P. H. Bates, of the United States Geological Survey, with the following result:

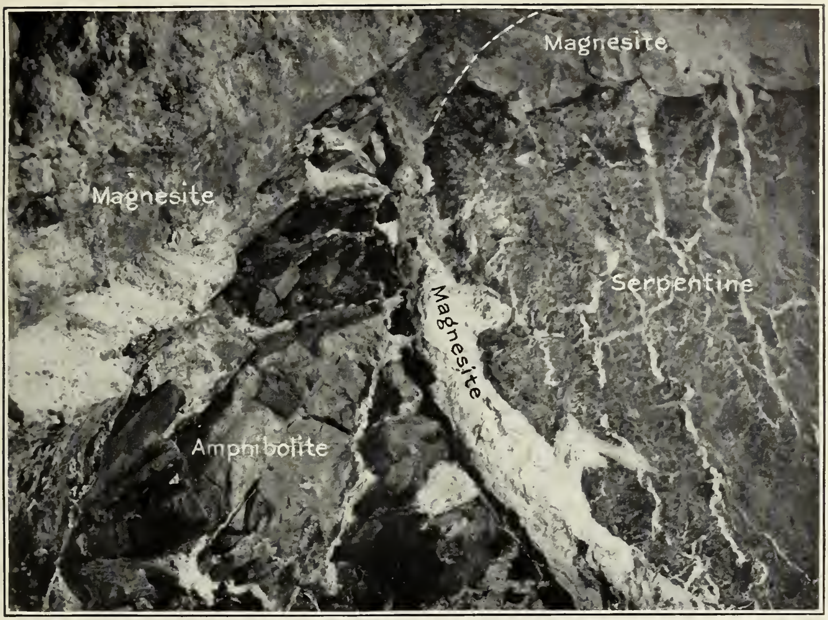
Partial analysis of magnesite from Deer Creek, Tulare County.

Silica (SiO_2)	0.31
Alumina (Al_2O_3)	.11
Ferric oxide (Fe_2O_3)	.08
Lime (CaO)	.24
Magnesia (MgO)	47.22
Carbon dioxide (CO_2)	51.64
	99.60

This is an excellent magnesite, the total impurities amounting to less than 1¼ per cent, but on the other hand the veins are small. The deposit is not more than 3 or 4 miles from the railroad, and may at some time pay to work.

On the east side, near the top of a somewhat higher hill adjoining this one on the south, other small deposits of magnesite occur. Several short veins up to 2 feet thick were seen. Another 30 inches thick is said to be located not far from the saddle between the hills.

Porterville deposits.—In the outer range of foothills, about 4 miles northeast of Porterville, magnesite veins stand out prominently on two rounded hills at the top of smooth, steep slopes, rising about 1,000 feet above the town. One of the hills, which will be referred to as the northern hill, runs a little east of north, and the other, which will be referred to as the eastern hill, about N. 60° E. At their junction is a saddle about 300 feet below the summits. The hills are free from brush or trees, and the broad San Joaquin Valley flattens smoothly away, so that the white veins standing above the surrounding rocks attract attention from considerable distances. W. P. Blake,



A. AMPHIBOLITE DIKE CUTTING THROUGH FLAT VEIN OF MAGNESITE, 4 MILES NORTHEAST OF PORTERVILLE.

Small magnesite veins have formed in the amphibolite.

B. CRUSHED MAGNESITE VEIN, 2 FEET WIDE, NEAR FURNACE 4 MILES NORTHEAST OF PORTERVILLE.

who passed through this region with the United States expeditions making explorations and surveys for a railroad in 1853, briefly described the deposits in his report.[a] Mining did not begin, however, until 1901, since when it has been carried on continuously. From 1902 up to the present time the mining has been done by the Willamette Pulp and Paper Company, which controls under lease the northern hill and the west end of the eastern hill. Charles S. Harker is the owner of both hills and still retains control of the larger part of the eastern hill. The veins occur in a brown serpentinized peridotite, having an apparent bedded structure. The serpentine forms part of a metamorphic complex consisting of a small amount of fine-grained quartzite, amphibolite schist, serpentine, and other magnesian rocks, some of which are talcose and mica bearing. The rocks have a general northerly strike, with a rather high (60°) easterly dip. They are cut off by a granitic mass on the south, a few hundred feet from the deposits. (See fig. 21.) Several granitic dikes cut the serpentine and other rocks, but do not cut the magnesite veins, though basic dikes (amphibolites) of several varieties cut both the country rock and the veins and are here and there squeezed to schist.

Faulting is common, but does not divide the serpentine into the small irregular blocks which result, in the serpentines of the Coast Range and many others, from the swelling of the rock as it changes its chemical and mineralogical form. However, movement is evident, and the magnesite is invariably crushed in the larger veins. In one vertical 2-foot vein a couple of hundred feet southeast of the kiln (Pl. IX, *B*) the magnesite has been so squeezed that it is left in irregular fragments whose sides are covered with abrasion lines, the whole looking as if at the time of crushing it had been in a semi-plastic state. In other veins the planes along which the magnesite has moved on itself are smooth and shaped so as to somewhat resemble the curve of a highly arched shell. Along many of these planes is a bright red stain of iron oxide, although the surrounding magnesite is pure white. In other places the magnesite has evidently been crushed almost to a powder and recemented.

It seems probable that the movements which have caused so much crushing and distortion have been due to other causes than the serpentinization of the peridotite, for, as stated, it is not badly shattered, nor does it show the great number of smooth faces, due to small internal movements, that are common under such circumstances. The movements here may have been due to the stresses occasioned by the raising of the Sierra Nevada, to the intrusion of the granite or the amphibolites, or to all of these causes.

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[a] Blake, W. P., Itinerary, or notes and general observations upon the geology, mineralogy, and agricultural capabilities of the route: Report of explorations in California, for railroad routes to connect with the routes near the 35th and 32d parallels of north latitude, Washington, 1856, p. 28.

Thin, nearly parallel veins of magnesite, mostly but a small fraction of an inch thick and but little farther apart, occupy zones in the serpentinized rock in which the sheeting due to shearing and crushing is especially prominent. These zones are practically vertical. The rocks have been fissured by faulting in many directions, and in the fissures magnesite veins have been deposited. Two of the largest veins occupying such spaces are practically flat. The veins range in thickness from threadlike seams to 8 feet, and the principal vein, which occurs in the northern hill (Pl. X, *A*), has been exploited through the hill, a distance of 785 feet, and can probably be followed through the valley between the hills and into the eastern hill. On the northern hill this vein ranges in thickness from 2 to 8 feet; it cuts the hill near the south end (see Pl. X, *A*, and fig. 2), strikes northwest, and dips steeply to the northeast. An amphibolite dike 2 to 3 feet thick has been intruded into the serpentine near the vein and follows it for a short distance. Along this stretch the vein has been squeezed to a schist; at other places it is comparatively fresh. About 100 feet from the southeastern outcrop of the vein it is joined by another vein of about the same thickness, having a strike of N. 10° W., which has also been mined.

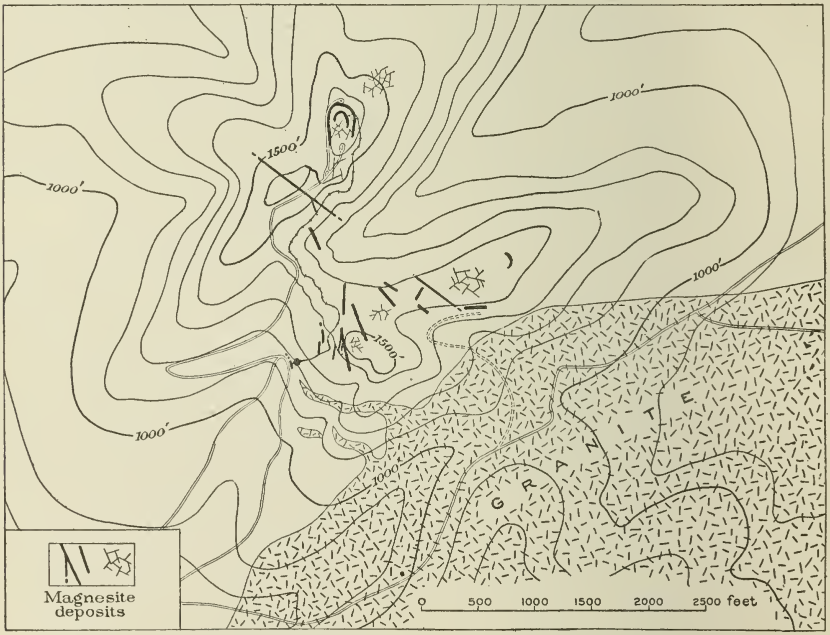


FIG. 2.—Plan of magnesite veins and workings 4 miles northeast of Porterville, Cal.

At the north end of the hill are two "blanket" or flat veins. The largest one (Pl. X, *B*) is practically horizontal in the middle part and

NORTHERN HILL AT WILLAMETTE PULP AND PAPER COMPANY'S MAGNESITE MINE NEAR PORTERVILLE, LOOKING NEARLY NORTH.

A, Nearly vertical vein; *B*, Lower "blanket" vein. The lower line ascending toward the right is a tramway; the upper one is a wagon road.

somewhat uplifted at both ends—north and south. It extends through the hill, a distance of 362 feet, and is probably longer than broad, and from 2 to 4 feet or more thick. A basic dike flattens and spreads under a large part of the vein in a thin sheet 1 to 2 feet thick; then, breaking through (Pl. IX, *A*), it overlies the remainder of the vein. Thin magnesite veins fill cracks in the dike, but the mass of the vein is cut by it. It is probable that small veins, similar to those in the dike, are being formed all through the hill at the present time. There is nothing to show that the vein has been tilted from a more upright position to its present place, and it was evidently formed as it lies, flat and cutting across the vertical structure of the serpentine. This is accounted for by supposing that there was a slow movement in the rocks along this plane at the time of the vein's deposition, the magnesite filling uneven open spaces along the horizontal fault, and that when there was another movement these deposits held the mass apart and made room for contiguous deposits. The crushed condition of the whole mass and the presence of inclusions of serpentine in lines approximately parallel to the sides of the vein give this hypothesis some color.

The other "blanket" vein lies above the north end of the vein just described. It dips at a rather low angle and will probably be found to run into the lower one.

Adjacent to all the larger veins are many small reticulated veins ranging up to 3 or 4 inches in thickness. At the north end of the deposits is a stockwork of small veins 2 to 6 inches thick (Pl. XI, *A*), and it is thought that it may pay to blast the whole mass and hand pick it. Between the blanket veins and the large vertical vein are a number of smaller veins, from the outcrops of which some hundreds of tons of magnesite can probably be broken. At the north end of the hill, below the blanket veins, there is also a considerable stockwork of veins which can probably be worked by blasting and hand picking.

On the west end of the eastern hill there are several veins of magnesite reaching a thickness of somewhat more than 3 feet, from which a small amount of magnesite has been mined.

W. P. Bartlett, the superintendent for the Willamette Pulp and Paper Company, has developed an excellent system of stoping the vein standing at a high angle. He first ran a tunnel through the hill, along the vein, somewhat less than 100 feet below the top. He then began to break down the magnesite from the roof at the farther end of the tunnel, allowing the waste to accumulate, so that the face of magnesite, which constantly retreats toward the portal of the tunnel, could be reached from the débris slope, down which the magnesite was rolled and removed in cars from the foot. This process is shown diagrammatically in fig. 3. The magnesite was entirely removed from above this level, and the same system is being worked on the level below, which is even with the tramway, and when this is worked out probably a still lower level may be worked on the same vein. Either underhand or overhand stoping, whichever is at the time more advantageous, can be carried on by this system.

The blanket veins require the removal of some waste rock, as the veins are not thick enough (from 2 to 4 feet) to permit economical working by mining out the magnesite alone. The waste is piled in the spaces already mined and forms a partial support for the roof. The roof is good and almost no timbering is required. A small amount of work has been done on some of the smaller veins, both on the northern hill and on the west end of the eastern hill. Practically all of the magnesite mined is calcined, and a tramroad, laid on such a grade that the cars run down by gravity, is built along the east side of the northern hill, through the saddle, to the kiln, which is located near the west base of the eastern hill. The veins are fortunately so situated that the tramway runs just under the blanket veins while maintaining its grade through the saddle. The kiln is located below the tramroad, so that the magnesite is dumped into a long chute through which it slides into the top of the kiln. (See Pl. XI, *B*, and fig. 4.) The magnesite is broken by hand at the tunnels to lumps 4 inches or less in diameter. Crude oil is used for fuel, and the magnesite gradually rises in temperature as it moves from the top downward through the kiln, until it reaches the flame from the burners. It is then raised to a white heat, and kept there for twenty to twenty-five minutes, when it is withdrawn from below. It is said that after this treatment 3 to 5 per cent of carbon dioxide still remains in the material. The air for the burners passes through the withdrawn material and is thus considerably heated.

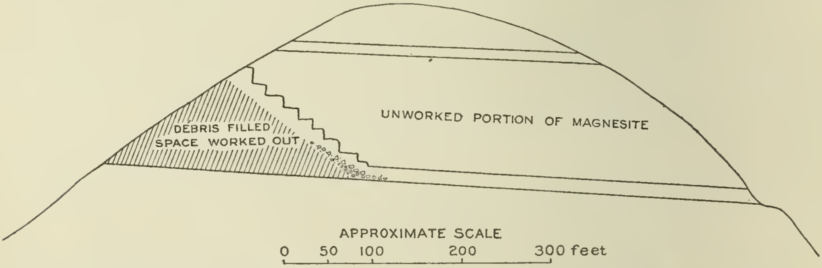
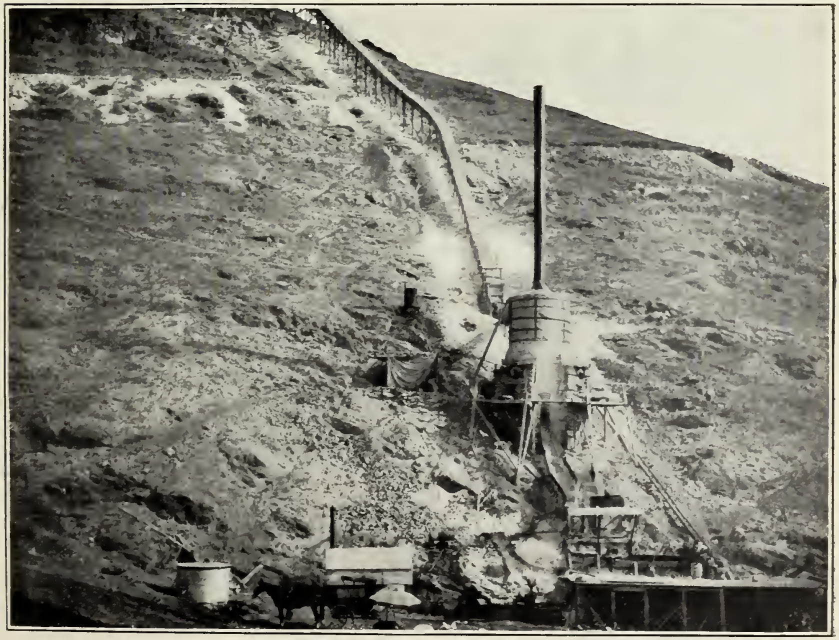


FIG. 3.—Diagram showing mode of working a highly inclined magnesite vein at Willamette Pulp and Paper Company's mine near Porterville, Cal.

A. OUTCROP OF STOCKWORK OF VEINS AT NORTH END OF WILLAMETTE PULP AND PAPER COMPANY'S DEPOSITS NEAR PORTERVILLE.

Broken magnesite ready for calcining in foreground.



B. FURNACE FOR CALCINING MAGNESITE AT WILLAMETTE PULP AND PAPER COMPANY'S MAGNESITE MINE NEAR PORTERVILLE.

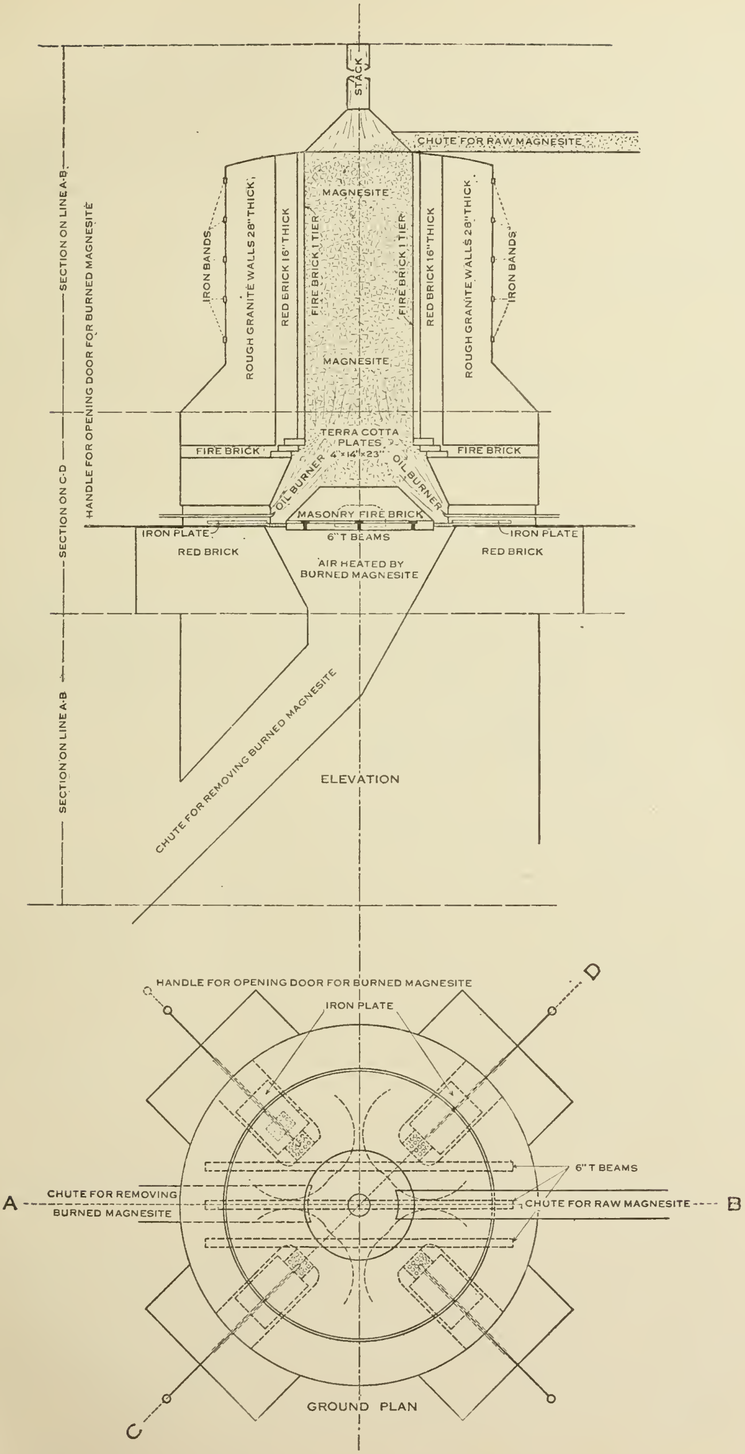


FIG. 4.—Elevation and plan of Willamette Pulp and Paper Company's furnace, 4 miles northeast of Porterville, Cal.

The following analyses of magnesite from this hill are at hand:

Analyses of magnesite from hill 4 miles northeast of Porterville.

	1.	2.
Silica (SiO_2)	2.28	0.90
Alumina (Al_2O_3)	.03	.49
Ferric oxide (Fe_2O_3)	.26	
Lime (CaO)	1.32	1.49
Magnesia (MgO)	45.17	44.39
Carbon dioxide (CO_2)	50.74	50.06
Water and undetermined	......	2.57
	99.80	99.90

1. Collected by the writer from tunnel No. 1 (in the large, highly inclined vein), and analyzed by A. J. Peters, of the United States Geological Survey.
2. Collected by W. P. Bartlett and analyzed by Abbot A. Hanks, of San Francisco, Cal.

The lime in these samples is probably too high to allow a good cement to be made, but as the operating company uses practically the entire product in wood-pulp whitening and digestion at its Oregon mills, this impurity is not particularly obnoxious.

In general the magnesite is white, but here and there it contains films of chlorite or serpentine where crushed. At other places there is a red stain of iron oxide on the surface of faces that have slipped on each other. Certain faces have been thinly coated with quartz, and one such face in which shrinkage cracks affect the quartz also is shown in Pl. VI, *B*.

The capacity of the furnace is from 27 to 29 tons of magnesite per day, giving 13 to 14 tons of magnesia. All shipments are made from Hilo spur, 1 mile north of the Porterville station.

On the eastern hill there are a large number of magnesite veins of dimensions similar (except in length, in which they are probably deficient) to those on the northern hill. The total amount of magnesite is probably considerably less; as already stated, one vein may be the extension of the main vein cutting the northern hill. No such flat veins as those described on the northern hill are to be seen here. In places the veins contain a considerable amount of serpentine in fine particles, and elsewhere the serpentine contains sufficient magnesite to give it a gray appearance.

A small amount of magnesite has been removed by open excavations and shipped by Charles S. Harker, the owner, to Oakland for the manufacture of carbon dioxide.

Deposits on South Fork of Tule River.—In a high hill on the southwest side of South Fork of Tule River are a large number of magnesite veins with outcrops ranging in thickness up to 20 feet. The magnesite veins seen are on the north side of the hill in secs. 30 and 31, T. 22 S., R. 29 E. They are less than a mile south of Success schoolhouse and about 9 miles from the railroad at Porterville. Should active work be undertaken, the road could probably be somewhat shortened. The haul is almost entirely down hill. An electric road from Porterville to Springville, which has been under contemplation for some time, if built, would pass within 3 miles of the deposits.

As Success schoolhouse is the most readily identifiable object in the landscape, the directions used in this description will be given with reference to it.

The portions of the hill containing the magnesite are composed of a rock much more completely serpentinized than that nearer Porterville. In the sections examined there are only scattered fragments of original minerals, probably pyroxenes, locally in radial crystals, which, in the hand specimen, reach 2 inches in length.

At the foot of the hill S. 26° W. (magnetic) from Success schoolhouse, a magnesite vein outcrops along the edge of the narrow flood plain of the river. The outcrop is from 3 to 10 feet thick, and is exposed prominently for a distance of about 500 feet, running northwestward, parallel to the river. In this distance it rises from the level of the flood plain to 60 feet above it at the southeast end. What is apparently the end of the outcrop, however, may be only the point to which it has been covered by débris from the hill slope, and at the other end it may run for some distance beneath the covering of soil. At each end, however, is a small watercourse, and in serpentine areas such channels very commonly mark fault lines. The magnesite is generally of a good white color, but is here and there grayish. In places the vein contains horses of serpentine, and at one place it is cut by a fine-grained basic dike, which is composed mainly of light-green amphibole and a fresh plagioclase feldspar with much magnetite, and which for most of the distance that it is visible runs approximately parallel to the vein.

On the assumptions that 5 feet is the average thickness of the vein and that it extends for 100 feet into the hill—both of which premises seem wholly reasonable—the vein would contain 500 (length) × 5 (thickness) ×100 (depth) = 250,000 cubic feet, which, on the basis of 11 cubic feet per short ton, is equivalent to about 22,700 tons.

A partial analysis of magnesite from this vein, made by A. J. Peters, gave the following result:

Analysis of magnesite from hill south of Success schoolhouse, Tulare County.

Silica (SiO_2)	0.80
Alumina (Al_2O_3)	.42
Ferric oxide (Fe_2O_3)	.20
Lime (CaO)	1.02
Magnesia (MgO)	45.94
Carbon dioxide (CO_2)	51.30
	99.68

The total impurities here amount to nearly 2.5 per cent, of which about 1 per cent is lime. There is probably enough lime to make it undesirable for the manufacture of cement, but it is a good material for use in paper, gas, or brick making.

The serpentine is in places full of thin parallel veins of magnesite, similar to those at the deposits near Porterville and Deer Creek. A couple of hundred feet above and west of the northwest end of the large vein just described are a large number of irregular magnesite nodules and masses, from which probably several hundred tons could be blasted at small cost. In the same neighborhood there are a number of smaller veins. About 200 feet (barometric measurement) above the flat vein is a fairly continuous outcrop reaching possibly 20 feet in thickness and 200 feet in length, in which the magnesite is of a beautiful pure-white color, but there are many inclusions of serpentine.

At a point S. 17° W. (magnetic) of Success schoolhouse and about 800 feet (barometric) above the river is a vein from 2 to 6 feet wide, which may be followed for about 200 feet. The strike is northwestward, with a high northeasterly dip.

On the top of the hill, at an altitude of over 1,000 feet above the river, are a number of veins ranging up to 6 feet in thickness, but most of them can not be traced far. One vein, averaging between 2 and 3 feet in thickness, was followed for 250 feet, and with greater care it may be possible to trace it farther. These veins are nearly a mile south of the flat vein first described, and in the intervening space are hundreds of irregular veins, which measure up to a foot or even more in thickness and which, in places near the river, form stockworks that could be blasted and hand picked at small expense.

The belt of serpentine carrying the magnesite has been crushed and sheeted in a northwesterly direction, and probably owes this structure to the forces that acted similarly on the magnesite-bearing serpentines nearer Porterville, which lie about 6 miles northwest. No development work has been done on these deposits.[a]

Round Valley deposits.—On the east side of the mouth of Round Valley, between 3 and 4 miles east of Lindsay, a number of magnesite veins ranging up to 2 feet in thickness crop out on the southwestern face of the hill, between 150 and 450 feet (barometric) above the floor of the valley. The country rock is serpentine, similar in macroscopic appearance to that at Porterville. The belt in which the veins occur has a northwestern trend similar to that of the deposits on South Fork of the Tule and of those near Porterville. The lower veins are of poor quality, as they contain a considerable amount of serpentine. The upper veins appear to be of good quality, but all are thin and too far

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[a] Since this paper went to press word has been received from Mr. W. P. Bartlett that he is now shipping magnesite from these deposits.

apart to be worked economically from the same opening. Hauling to the Southern Pacific Railroad at Lindsay would be easy and on down grade all the way.

Deposits near Exeter.—Magnesite had been reported to the writer as occurring in a number of the orange orchards east of Exeter, where it was said to be killing the trees, but in each case the substance was found to be carbonate of lime. However, on the southwest spur of Rocky Hill, 2 miles east of Exeter, there are a few small veins of magnesite about 500 feet above the valley. The largest vein is not more than a foot wide, and most of them are only from 1 to 3 inches wide. The area over which the veins occur is very small and the deposits are without economic value.

A vein of californite, a variety of vesuvianite, occurs alongside the magnesite. It is said to have been worked under the supposition that it was impure chrysoprase. From the matter thrown out the vein appears to be from 2 to 4 inches wide. The rock in the shaft was so much shattered and coated with calcareous material that the vein could be but imperfectly made out. The color of the californite is rather irregular; the ground color is a light green, carrying a hint of yellow, but through this are sprinkled small spots of buff or white, and spots about one sixty-fourth of an inch across of dark green.

Deposits of magnesite were reported in the Yokohl Valley, a few miles east or southeast of Exeter, but they could not be definitely located.

Naranjo deposits.—George D. Ward, of Oakland, is interested in some small deposits of magnesite about 7 miles northwest of Lemon Cove and 1 mile northwest of Naranjo post-office. The deposits are situated in a serpentine hill containing many intrusions of greenstone and granite. Most of the veins are from 2 to 5 inches thick and are exposed for only a few feet. They are in general of rather pure-looking but spongy material though some have considerable serpentine mixed with them. The largest vein is situated on the north side of the hill and is but 16 inches thick. A small excavation has been made, and this affords the only exposure. The vein is much crushed and the magnesite appears to be of only fair quality. At a number of places on the hill are veins, 1 to 2 inches thick, of translucent white nonprecious opal.

Other Tulare County deposits.—Small veins of magnesite are reported to occur near Auckland, but they are probably of little importance. There are undoubtedly other veins, which may or may not be of value, in the great areas of serpentine that lie along the foothills of the Sierra Nevada through the entire length of the county.

FRESNO COUNTY.

Nine miles east of Sanger George D. Ward has located magnesite claims on both sides of Kings River, near what is known as Red Hill. The country is one of rather high, smooth, nearly treeless hills, rising perhaps somewhat over 1,000 feet above the river. The rocks are metamorphic and include some serpentine and partially serpentinized tuff. They are all in comparatively narrow bands, and, except the serpentine, are gneissoid. Much of the rock was originally granite or diorite. All the rocks have a structure much resembling bedding. The amount of magnesite in sight seems, at first glance, remarkably large for the amount of serpentine present.

On the north side of the river the principal vein is on what is known as the Snow Cap claim. The vein outcrops about half a mile from the river, in a small embayment in the hills. A face has been exposed showing the magnesite to be at least 8 feet thick. (See Pl. XII, *B*.) It has a strike of N. 24° W. (magnetic) and an easterly dip of about 75°, which probably agree with the strike and dip of the country rocks. On the foot wall is a considerable amount of soft, friable magnesite, which is very much like calcareous tufa and which is, in fact, a magnesian tufa. This deposit is more than a foot thick. About 3 feet from the foot wall is an irregular vein of magnesite, from 6 inches to 3 feet thick, which probably joins the main vein a short distance below, and which could be economically mined with it. The vein can be definitely followed for about 600 feet to the north, across a low hill, and seems to get thinner toward the farther end. The magnesite is a clear white, containing serpentine only here and there.

A partial analysis of a specimen of fine-grained pure-white magnesite from the body of the vein, collected by the writer and analyzed by A. J. Peters, was as follows:

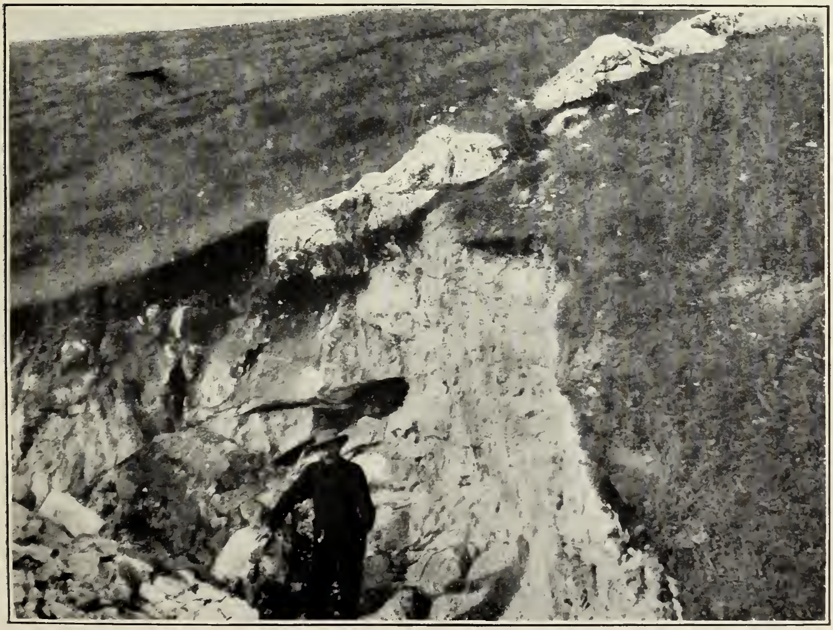
Analysis of magnesite from large vein, Snow Cap claim, Kings River.

Silica (SiO_2)	0.20
Alumina (Al_2O_3)	.04
Ferric oxide (Fe_2O_3)	.12
Lime (CaO)	.96
Magnesia (MgO)	46.48
Carbon dioxide (CO_2)	51.80
	99.60

It will be noticed that there is nearly 1 per cent of lime in the specimen, although a commercial analysis made for Mr. Ward was said to show none.

A quarter of a mile north from the end of the vein, along the same strike, is a vein of rather impure magnesite. The dip is shallower and it is not likely that the two veins are connected.

A. MAGNESITE VEIN ON SOUTH SIDE OF KINGS RIVER, 9 MILES EAST OF SANGER.



B. MAGNESITE VEIN ON SNOW CAP CLAIM, NORTH SIDE OF KINGS RIVER, 9 MILES EAST OF SANGER.

A couple of hundred feet up the ridge, west from the main outcrop of the Snow Cap, is a magnesite vein of good quality from 10 to 21 inches wide, which may be followed for 100 to 150 feet. It is on the Snow Cap claim. On the same claim, in the gulch on the south, 200 feet from the main outcrop of the Snow Cap and just below an old wagon road, a mass of fine white magnesite showing a surface of 8 by 13 feet has been uncovered. At the time of visit not enough work had been done to show whether the occurrence was a vein or a large nodule.

On the Governor claim, a quarter of a mile S. 16° W. from the main Snow Cap outcrop, across a gulch and about 100 feet (barometric measurement) above the Snow Cap, is a small outcrop of a magnesite vein of good quality, dipping highly S. 60° E. It is probably 2 feet thick and has been exposed for a length of 10 feet. Magnesite float, which has been found 300 feet or more to the southwest, has been supposed to come from the extension of this vein, but there is nothing at present shown to prove it.

Besides the vein mentioned there are at a number of places smaller veins, largely of noncompact magnesite. The surfaces of the spongy magnesite are colored a fine pink. Small red lichens grow upon the magnesian rocks of this vicinity, and if treated with an alkali (sodium hydrate or ammonia) they give the same pink hue, so that the color may be derived from these lichens, or it may be due to some iron compound. No other coloring material, such as cobalt or manganese, which would account for it could be detected in the specimens.

On the south side of Kings River, about half a mile from and 650 feet above the stream, is a fine large vein of magnesite, which runs east and west across a northward-projecting hill. (See Pl. XII, *A*.) The vein as exposed at the time it was visited was at least 8 feet wide and may have been somewhat wider. It could be readily traced for about 200 feet, but no attempt had been made to show its length by excavations, so that it may prove to extend farther. The magnesite seemed to be of good quality, with but few inclusions of serpentine.

The deposit is reached by a fairly easy grade and could be very economically worked. The haul from the deposits on both sides of the river to the railroad at Sanger is all downhill except for trifling grades, and in general the roads are excellent. The magnesite from the two sides would, however, have to go by different roads, owing to the difficulty of fording the river.

MARIPOSA AND TUOLUMNE COUNTIES.

Large bodies of magnesite containing green mica and pyrite have occasionally been reported from Mariposa and Tuolumne counties, but probably most if not all of the deposits referred to are dolomite containing large amounts of mariposite, a chrome mica. There are in these counties, however, belts of serpentine in which it would not be surprising to find magnesite, though the writer's inquiries have so far located none.

PLACER COUNTY.

Damascus deposits.—Many statements have been published from time to time heralding the deposits near Damascus as "the largest in the State," possibly because they are among the least convenient to reach. The writer did not visit the locality, as at the time he was in this portion of the State the deposits were reported to be covered with snow. The magnesite is in the S. ½ sec. 18, T. 15 N., R. 11 E., 3 or 4 miles from Damascus and Michigan Bluff and probably not more than 10 miles in a direct line from Colfax. The following information was kindly furnished by Mr. Harold T. Power, of Bullion, Cal., and Mr. H. W. Turner, formerly of the United States Geological Survey, but now of Portland, Oreg.

In the southwest quarter of the section the deposits are located just below the Morning Star ditch, in a serpentine country rock. Besides a number of small veins an inch or so in width, there are several lenses of magnesite forming practically one body about 30 feet in width and 100 feet long, which contains some serpentine. A specimen sent in by Mr. Power is of good appearance, though not very compact. As no analysis has been made, its composition can not be given. A small exposure of a 2-foot vein is said to occur in the southeast quarter of the section.

The country is so rough that under present conditions the magnesite can not be mined at a profit. A lumber railroad has been surveyed to run close to the deposits, and should such a road be built they might be worked.

W. P. Bartlett, of Porterville, reports a 2-foot vein of magnesite in the canyon of American River, near this place, but on account of its unfavorable location it is valueless. Other small veins also have been reported, but so far nothing of value has been found.

MAGNESITE DEPOSITS IN OTHER COUNTRIES.

It is always desirable to know something of mineral deposits which may be possible or certain competitors in any mining or quarrying enterprise. California's commercial isolation from the eastern portion of the United States, caused by the long railroad hauls, precludes railroad shipment of products that sell as cheaply as magnesite. Owing, however, to the possibility of shipping by water with a fair margin of profit, the following notes on competing foreign deposits are given.

NORTH AMERICA.

CANADA.

Quebec.—Magnesite occurs at a number of places in the Dominion of Canada, but the deposits known seem to be remarkably different from those of California. In eastern Canada magnesite has been found in the township of Grenville, Argenteuil County, Quebec,[a] in place and in loose bowlders, some of the latter weighing many tons. In appearance this magnesite is granular and much like clear, rather coarse grained marble, and it is supposed to be of sedimentary origin. One outcrop is about 100 feet wide and a quarter of a mile long. If it is a sedimentary deposit it is unique, so far as has come to the attention of the writer, as nowhere else are magnesian sediments known in which the percentage of magnesium carbonate present exceeds to any appreciable degree the theoretical amount contained in dolomite (45.65 per cent). Although limestones carrying any percentage of magnesium carbonate up to 45.65 may be found, the remainder of the series between 45.65 and 100 per cent have had no representatives until the discovery of these deposits. Analyses by the Geological Survey of Canada of various specimens showed magnesium carbonate, 49.71 to 95.50 per cent; calcium carbonate from a "very small amount" to 30.14 per cent; and magnesia other than carbonate (probably nearly all serpentine), 3.08 to 9.17 per cent.

An average of 57 samples from another locality gave—

Average composition of magnesite from Quebec.

Magnesium carbonate	81.27
Calcium carbonate	13.64
Magnesia other than that present as carbonate	3.66
	98.57

British Columbia.—In the Atlin district of British Columbia, at the town of Atlin,[b] deposits of hydromagnesite ($3MgCO_3.Mg(HO)_2+3H_2O$) occur in Pine Creek valley as a fine white powder covering several acres and known to be as much as 5 feet deep. The deposits are evidently derived from springs, the waters from which carry 1.834 parts of magnesia in 1,000. Hydromagnesite when pure carries 43.9 per cent of magnesia, 36.3 per cent of carbon dioxide, and 19.8 per cent of water.

Similar deposits[c] occur at the 108-mile House on the Cariboo road

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[a] Hoffman, G. C., Report of the section of chemistry and mineralogy: Ann. Rept. Geol. Survey Canada, vol. 13 (for 1900), pt. R, 1903, pp. 14–19.

[b] Gwillim, J. C., Report on the Atlin mining district, British Columbia: Ann. Rept. Geol. Survey Canada, vol. 12, pt. B, 1899, pp. 47–48.

[c] Hoffman, G. C., Report of section of chemistry and mineralogy: Ann. Rept. Geol. Survey Canada, vol. 11, 1900, pp. 10–11.

93 miles north of Ashcroft, Lillooet district, British Columbia, where they are scattered over 50 acres or more of ground. At three or four places patches of the material 50 to 100 feet wide stand a foot or more above the general surface. At one point a shaft showed the deposit to be over 30 feet thick.

At Atlin an exceedingly impure magnesite occurs with serpentine and dunite,[a] and is said to be over 1,000 feet wide on the Anaconda group of claims. It is impregnated with iron pyrites, and is cut by apple-green quartz carrying 1 pennyweight of gold per long ton and 15 per cent of nickel. A partial analysis of the magnesite is as follows:

Partial analysis of magnesite from Atlin, British Columbia.

Magnesia (MgO)	21.70
Protoxide of iron (Fe_2O_3)	5.10
Carbonic acid (CO_2)	27.00
Silica (SiO_2)	45.68
Combined water and loss	0.52
	100.00

Under present conditions these British Columbia deposits are probably without economic value.

MEXICO.

Lower California.—On the island of Santa Margarita, in Magdalena Bay, extensive deposits of magnesite have recently been examined by Julius Koebig, of Los Angeles, for a firm of that city. The country rocks are said to be sandstone, quartzite, and syenite. No mention is made of more magnesian rocks, though it seems highly probable from the amount of magnesite described that such rocks are present. The island is mountainous and is 25 miles long by 4 or 5 miles broad. Doctor Koebig says in his report:

> Practically every canyon of the Sienite Mountains, by decomposition of the eruptive rocks, shows larger or smaller deposits covering in some instances the entire surface of hills and mountain sides. The banks of the canyons, where the rocks have been cut by the streams during the rainy season, show magnesite strata several feet thick, and for a distance of a few hundred feet to over a mile the arroyo itself contains large quantities of magnesite in the shape of bowlders, weighing from a few pounds to 3 to 5 tons apiece. * * * Estimated in the most conservative way, I have seen actually in sight on the surface, and in no case more than 1½ miles from shore, 300,000 to 500,000 tons ready to be picked up and packed to the beach without the use of any tools other than a sledge hammer. * * * For labor there are plenty of Mexicans to be had at not to exceed $1.50 Mexican per day. * * * As means of transportation to the wharf there are 300 or more donkeys on the island. * * * There is plenty of water for a crew of Mexicans and the pack animals.

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[a] Gwillim, J. C., op. cit., pp. 21-22.

The following analyses are given in the report:

Analyses of magnesite from Santa Margarita Island, Lower California.

	1.	2.
Insoluble, sand and clay	Trace.	0.06
Ferric oxide (Fe_2O_3) Alumina (Al_2O_3)	0.21	.10
Carbonate of lime ($CaCO_3$)	.43	
Lime (CaO)		Trace.
Carbonate of magnesia ($MgCO_3$)	99.36	
Magnesia (MgO)		99.05

1. Raw magnesite; analyst unknown.
2. Calcined magnesite; analysts, Baverstock & Staples, Los Angeles, September 13, 1907.

The company offers to furnish the magnesite for $3.50 f. o. b. vessel at Santa Margarita.

Other deposits of magnesite are reported from various parts of Mexico, but little is known of them.

SOUTH AMERICA.

VENEZUELA.

The Venezuelan Government has recently granted for twenty-five years the exclusive privilege[a] of exporting magnesite found on private lands on the island of Margarita, to a company which expects to ship from 12,000 to 15,000 tons annually. Nothing further is known of the deposits.

Dana[b] quotes N. S. Manross as stating that magnesite occurs near Mission Pastora, in Canton Upata.

EUROPE.

AUSTRIA.

Styria in Austria has very large deposits of magnesite which are actively worked. The largest company is the Veitscher Magnesitwerke Actiengesellschaft,[c] with mines at Veitsch, 5 miles from the Mittersdorf Murzthal railway station. During 1903 this company produced 71,016 tons of magnesite and shipped to the United States 35,000 tons of the calcined product.

This company and the Magnesite Company, Limited, of Hungary, have a working agreement.[d]

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[a] Moffat, T. P., Daily Consular and Trade Repts., No. 3108, Washington, February 25, 1908, p. 8.

[b] Dana, E. S., Descriptive mineralogy, 6th ed., New York, p. 275.

[c] Rublee, W. A., Daily Consular Repts., No. 2276, Washington, June 6, 1905, p. 2.

[d] Private letter.

HUNGARY.

The Magnesite Company, Limited,[a] with headquarters at Nyustya, Gomor County, is the largest company operating in Hungary. The veins worked are very large, ranging from 150 to 300 feet in width, and are worked as open quarries, with stages from 40 to 60 feet high. The magnesite is yellowish or bluish white, in some places fine grained and in others of very coarse crystalline structure. The following analyses of the magnesite, of which No. 2 is calcined, are given as representative:

Analyses of Nyustya magnesite.

	1.	2.
Silica (SiO_2)	0.74- 0.76	1.67
Alumina (Al_2O_3)	.39- .27	3.47
Ferric oxide (Fe_2O_3)	3.27- 3.43	4.68
Lime (CaO)	1.20- .90	2.94
Magnesia (MgO)	44.80-45.00	86.90
Carbon dioxide (CO_2)	50.10-50.20	....

The output of dead-burned magnesite of the company in 1904 (1905?) was 22,000 to 23,000 tons from Nyustya and 11,000 to 12,000 tons from Jolsva and Ochtina. The company was at that time making 750,000 magnesite brick per year.

The production of magnesite in Hungary during 1907 was as follows:[b]

Production of magnesite in Hungary, 1907.

	Quantity.	Value.
	Quintals.	*Crowns.*
United Magnesite Company, Nyustya	98,000	519,000
Company of Magnesite-Industry:		
Nyustya (Gomor)	1,090	10,877
Jolsva (Gomor)	1,126	
Martonhaza	437	
General Magnesite Company, Hizsnyo (Gomor)	78,000	330,000
	178,653	859,877

The product is equivalent to 19,693 short tons, valued at $174,554. The whole output was made into brick.

Besides brick and calcined magnesite, the Hungarian companies ordinarily make "caustic" or partly calcined magnesite for use as a mortar, with which magnesite brick are set.

GERMANY.

Deposits of magnesite were worked for many years in the neighborhood of Frankenstein, Silesia.[c] The magnesite is said to occur in

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[a] Private letter.

[b] Letter from director substitute, Mining Dept., Royal Hungarian Geol. Inst., April 24, 1908.

[c] Squire, Lovell, jr., Some observations on the magnesite of Silesia: Trans. Royal Geol. Soc. of Cornwall, vol. 9, pt. 1, 1875, pp. 59-70.

"nests," probably similar to what are called "bowlders" in California; that is, in large nodules. The deposits are covered with soil, and the peasants dig at random for it. The analysis was given as follows:

Analysis of magnesite from Frankenstein, Silesia.

Silica (SiO_2)	5.60
Alumina (Al_2O_3)	.85
Calcium carbonate ($CaCO_3$)	.40
Magnesium carbonate ($MgCO_3$)	93.00
	99.85

As would be expected from the lack of iron or other coloring matter, the magnesite is said to have been very white. It is not known whether the deposits are still worked. Some chrysoprase was found in veins close by.

GREECE.

The principal magnesite deposits of Greece are located on the island of Eubœa.[a] The Anglo-Greek Magnesite Company, Limited, operates magnesite quarries belonging to the Galataki monastery, 10 miles from the port of Limni, whence the magnesite is shipped. The output of this company during 1902 and 1903 was as follows:

Magnesite output of Galataki quarries and exports to the United States, 1902 and 1903.

[Short tons.]

	Raw magnesite.		Caustic calcined magnesite.		Dead-burned magnesite.
	Output.	Exported to the United States.	Output.	Exported to the United States.	
1902	14,600	6,647	3,500	578	
1903	26,300	3,200	3,550	125	1,200

The Society of Public Works of Athens is exploiting magnesite deposits by underground workings at Mantudi and Limni. During 1902 it shipped to the United States 7,390 metric tons of magnesite and 92 tons of fire brick; in 1903, 2,335 tons of magnesite; in 1905, 22,747 tons of magnesite; and in 1906, 32,194 tons of magnesite, which was produced at Mantudi.[b] The total output for Greece in 1905[c] was 47,849 short tons, and in 1906, 71,015 short tons, valued at $168,376 and $283,333, respectively. Magnesite is also found at Xirochori, on the island of Eubœa; near Mariki, close to Thebes (Bœotia); and at Hermioni, in Argolis.

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[a] McGinley, Daniel E., Daily Consular Reports, No. 2276, Washington, June 6, 1905, pp. 3, 4.

[b] Bergbau in Griechenland: Zeitschr. angew. Chemie, vol. 21, January 31, 1908, p. 225.

[c] Quoted "from a Government report" in Min. Jour. (London), vol. 82, 1907, p. 633.

Analyses of fused Grecian magnesite from unknown mines gave Fitzgerald & Bennie [a] the following figures:

Analyses of Grecian magnesite (mines unknown).

	1.	2.	3.	4.	5.
Silica (SiO_2)	0.69	1.82	2.50	2.24	2.21
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	1.79	1.76	3.45	2.05	3.20
Lime (CaO)	3.29	1.74	1.10	2.48	1.85
Magnesia (MgO)	93.68	94.37	92.80	93.63	93.27
	99.45	99.69	99.85	100.40	100.53

ITALY.

Magnesite occurs at Casellette, in the Val di Susa, and at several other places in the Turin district, and on the island of Elba. None of the deposits seem to be of very large size. During 1906 the Turin district produced 1,463 short tons of raw magnesite,[b] valued at $3,958, and 220 tons of calcined magnesite,[c] valued at $2,180.

The Casellette deposits[d] consist of great numbers of roughly parallel small veins up to a few inches thick, in a serpentinized lherzolite. They are close enough together so that the rock can be broken down and hand picked.

No production was reported from the island of Elba, though the deposits have been worked in former years. The deposits are stockworks of small veins[e] in a serpentinized lherzolite and are apparently similar to those at Winchester, Cal. (See p. 38.) The following analyses of the Elba magnesite are given by D'Achiardi:

Analyses of magnesite from the island of Elba.[f]

Water (H_2O) at 110° C	1.82	2.28
Water (H_2O) above 110° C	1.68	2.08
Carbon dioxide (CO_2)	44.70	43.86
Silica (SiO_2)	8.15	8.65
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	Trace.	.10
Lime (CaO)	3.50	.99
Magnesia (MgO)	40.84	42.05
	100.69	100.01

MACEDONIA.

Magnesite is found in large quantities[g] in Macedonia near the coast, not far from the Greek border. Some of the veins stand out

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[a] Physical properties of fused magnesium oxide: Trans. Am. Electrochem. Soc., vol. 9, 1906, p. 102.

[b] Rivista del Servizio Minerario, 1906, Roma, 1907, p. xlix.

[c] Op. cit., p. liii.

[d] Piolti, Giuseppe, Sull' origine della magnesite di Casellette (Val di Susa): Mem. della Accad. sci. Torino, 2d ser., vol. 47, pp. 126-142.

[e] D'Achiardi, G., La formazione della magnesite all' Isola d' Elba: Atti (Mem.) Soc. toscana sci. nat., Pisa, vol. 20, 1904, pp. 86-134.

[f] D'Achiardi, G., op. cit., pp. 123, 129.

[g] Der Bergbau in Mazedonien: Montan Zeitung (Graz, Austria), vol. 15, January 1, 1908, p. 10.

like walls and may be seen from the sea. Little work has been done on them, but in 1906 a new mine on the Chalkidike Peninsula began operations, and a furnace was put up.[a]

NORWAY.

Magnesite is being mined from deposits in Norway at Snarum,[b] in the Modums division of Buskerud bailiwick, on the Kroder line, a spur of the Drammen Randsfjord line, 56 kilometers (35 miles) from Drammen, the nearest city and port. The magnesite is found in serpentinized olivine rocks which occur with schists and quartzites. Some of it is crystallized in rhombohedra, but such deposits are generally small. The main deposits are ordinarily granular. In both forms the magnesite is nearly pure white, though the granular magnesite contains some serpentine, which occurs in more or less distinctly marked bands or in grains up to the size of a bean, rather evenly distributed through the mass. The included serpentine is used to sinter the material in burning the brick.

There are two principal fields—the Dybingdals, 3 miles north of Snarum station, and the Langerud field, 1⅓ miles west of Snarum station. In the former the magnesite area covers about 1,200 square meters. The veins average about 13 feet in width, and dip 30° and upward. They are worked by underhand stoping. In the Langerud field magnesite is exposed for 135 feet along Snarum or Halling River, and also 100 yards farther southwest. There are also smaller deposits in the neighborhood of these fields. A factory, which has a capacity of about 2,500 tons of brick per year, is operated near Snarum.

The magnesite is sold calcined or as brick. An analysis of the brick is as follows:

Analysis of magnesite brick made at Snarum, Norway.

Silica (SiO_2)	9.3
Manganous oxide (MnO)	.05
Aluminum sulphate ($AlSO_4$)	2.00
Iron oxide (Fe_2O_3)	4.60
Phosphoric anhydride (P_2O_5)	.046
Sulphur (S)	.003
Lime (CaO)	.00
Magnesia (MgO)	83.600
Loss by heating	.50
	100.099

The magnesite is remarkable in that it shows no lime. According to tests quoted in the article referred to, brick from the Snarum factory are more heat resistant than the Austrian Veitsch brick.

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[a] The mineral wealth of Macedonia: Mining Jour. (London), vol. 83, 1908, p. 251.

[b] Daumann, E., Magnesit fran Snarum: Bihang till Jern-Kontorets Annaler for 1905, Stockholm, 1905, pp. 222-235.

During 1907 [a] the output of the works was 900 tons of calcined magnesite, valued at $12,060, and 125 tons of brick, valued at $3,685.

RUSSIA.

Magnesite occurs in Russia in the Uphim Mountain district of the Urals, and during 1906 one firm, the Magnesite Company, produced 26,320 tons of magnesite. [b]

AFRICA.

TRANSVAAL.

Extensive deposits of magnesite occur between Kaapmuiden and Malelane, 2 miles south of the Pretoria-Delagoa Bay Railway, 87 miles from Lourenço Marquez and 300 miles from Johannesburg. The magnesite is found in a great number of veins, ranging up to 4 feet in thickness, and has been exploited to a depth of 95 feet.[c] Most of the veins are much thinner than the limit of width given, but there seems to be a large area of serpentine carrying them. The serpentine is here 3 miles wide. Some of the magnesite is soft and powdery, like that at Red Mountain, Santa Clara County, Cal. (p. 35).

One 4 to 6 inch vein [d] is described as "entirely of pure, glassy-looking magnesite." Hall gives the following analysis of a picked specimen from these deposits:

Analysis of magnesite from Malelane, Transvaal.

Magnesia (MgO)	45.272
Carbon dioxide (CO_2)	49.80
Silica (SiO_2)	2.30
Lime (CaO)	......
Ferric oxide (Fe_2O_3)	.80
Moisture at 110° C	.16
	98.332

Quartz forming thin coatings on the magnesite is found at various places.

The rock is used for making carbon dioxide, and much of it is calcined by producer gas at about 1,100° C. and mixed, either in lump or ground, with magnesium chloride imported from Germany to make oxychloride cement. Most of the output goes into this product, for which its freedom from lime makes the material particularly well suited.

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[a] Letter from Dr. Johan H. L. Vogt, professor of metallurgy at the University of Kristiania, February 15, 1908.

[b] Magnesite and chrome iron ore in the Urals: Mining Jour. (London), vol. 82, December 14, 1907, paragraph on p. 721.

[c] Hall, A. L., The magnesite deposits of Malelane: Rept. Geol. Survey, Transvaal Mines Dept., for 1906, Pretoria, 1907, pp. 127-132.

[d] Hall, A. L., op. cit., pp. 128-129. For further reference to the Malelane deposits see Hollis, W. S., Magnesite deposits in South Africa: Daily Consular Repts., No. 2276, Washington, June 6, 1905, pp. 7-8; Praagh, L. V., The Transvaal and its mines, London and Johannesburg, 1906, pp. 633-634.

OTHER AFRICAN DEPOSITS.

Henry W. Nevinson [a] speaks of "the volcanic district of North Bihé, with its boiling springs and great deposits of magnesia." The Bihé region is a couple of hundred miles east of Benguela, in Portuguese West Africa. No further details are given, but the association with boiling springs suggests that such a magnesian deposit would probably be hydromagnesite, similar to the deposits in British Columbia. (See p. 53.)

"Magnesia," [b] by which magnesite is probably meant, is reported to occur in Mashonaland, near the western side of Africa, notably at Umtali and at the great Zimbabwe ruins—at the latter place in steatite.

ASIA.

INDIA.

Madras.—Magnesite is found at a number of places in India, the most important of which seems to be in the Chalk Hills, 4 miles northwest of Salem, Madras Presidency, in the southern part of the Indian Peninsula. The magnesite here occurs in interlacing veins, some of which stand several feet above the surrounding talcose, serpentinized, and other magnesian rocks. From the whiteness of the outcropping magnesite the name "Chalk Hills" has been given to the range. The main magnesite deposits occur over an area of 10 square miles,[c] and there are various outlying deposits. During 1905 the production was 2,035 tons of magnesite, valued at $2,750, and during 1906 1,832 tons, valued at $2,440.[d]

Mysore.—Magnesite deposits occur at a number of points near Mavinhalli and Kadakola, in Mysore,[e] in the south-central part of the Indian Peninsula. The deposits do not seem to be of commercial importance at present, though the magnesite has been used locally as a substitute for lime.[f] There are also reported to be many deposits of magnesite in the neighborhood of Yelwal,[g] but their extent is unknown.

Ceylon.—"Hydromagnesite does not occur in commercial quantities so far as known, but has some local use." [h]

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[a] The slave trade in Africa: Harper's Magazine, vol. 112, December, 1905, p. 116.

[b] Swan, Robert M. W., Notes on the geography and meteorology of Mashonaland, in Bent, J. T. Ruined cities of Mashonaland, London, 1892, p. 347.

[c] King, W., jr., and Foote, R. B., On the geological structure of the districts of Trichinopoly, Salem, and South Arcot included on sheet 79 of the Indian atlas: Mem. Geol. Survey India, 1865, pp. 312-327.

[d] Dennison, E. Haldeman, Daily Consular Repts., No. 3138, Washington, March 31, 1908, pp. 1-2.

[e] Primrose, A., Notes on magnesite in the Mysore district: Rec. Mysore Geol. Dept., vol. 4 (1904?), pp. 147-157.

[f] Op. cit., p. 151.

[g] Ram, B. Jaya, Summary of the work done during the year 1904-5: Rec. Mysore Geol. Dept., vol. 6 (1906?), p. 52.

[h] Parsons, James, principal mineral surveyor for Ceylon, letter, March 5, 1908.

AUSTRALIA.

QUEENSLAND.

In Queensland [a] magnesite occurs in the Normanton district in the Gulf country; in the Rockhampton district on Dinner, Sawpit and Stewarts creeks; at Stanwell, Islapot, Moonmera, and the Pointer, near Yamba. In other districts it occurs at Clermont, Toorwomba, Ipswich, Kilkivan, and Newellton. The deposit at Kilkivan is thought to be the largest, though all the deposits are so small that it is improbable that any of them can be worked commercially.

NEW SOUTH WALES.

Small deposits are known in New South Wales [b] in the diamond fields at Bingera, county of Murchison, and near Mudgee. At Two-mile Flats, near Mudgee, pebbles in waste heaps were cemented together by it. On Cudgebegong Creek it forms in peculiar vermicular or wormlike forms. Other localities in New South Wales are Lochlan River, Mooly Gully, and Scone, county of Brisbane; Louisa and Lewis Pond creeks, county of Wellington; and Barraba, county of Darling. None of these deposits are of commercial value, but recently magnesite has been discovered in what appears to be considerable quantity [c] 3½ miles northwest of Fifield. Over an area of 100 acres it crops out through red clay as large rounded blocks of pure-white material. It is said to be capable of yielding many thousand tons of magnesite at a cost not exceeding 38 cents per ton, on drays. A partial analysis of this magnesite is as follows:

Partial analysis of magnesite from Fifield, New South Wales.

Magnesium carbonate ($MgCO_3$)	99.01
Lime (CaO)	Absent.
Ferric oxide (Fe_2O_3) Alumina (Al_2O_3)	.54
Gangue (sand)	.42
	99.97

SOUTH AUSTRALIA.

Large deposits are reported in South Australia, but so far no work has been done on them.

TASMANIA.

In Tasmania magnesite "occurs in serpentine, Parson's Hood Mountain; in veins, Trial Harbor; Meredith Range; Dundas; Hazlewood."[d]

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[a] Dunstan, B., Magnesite in Queensland, quoted in Queensland Gov. Min. Jour. (Brisbane), vol. 8, August, 1907, p. 405.

[b] Liversidge, Archibald, The minerals of New South Wales, 2d ed., Sydney, 1882, p. 176.

[c] Jaquet, J. B., Magnesite at Fifield: Australian Min. Standard, vol. 38, 1907, p. 172.

[d] Petterd, W. F., Minerals of Tasmania: Papers and Proc. Royal Soc. Tasmania, 1893, Hobart, 1894, p. 45.

OCEANICA.

NEW CALEDONIA.

Extensive deposits of magnesite occur on the north end of the west coast of New Caledonia,[a] at the contact of black schists with serpentine, particularly between Koumac and Voh. A specimen obtained near Koumac gave the following analysis:

Analysis of magnesite from vicinity of Koumac, New Caledonia.

Silica and insoluble (SiO_2, etc.)	0.8
Ferric oxide (Fe_2O_3)	.8
Lime (CaO)	3.3
Magnesia (MgO)	42.4
Carbonic anhydride (CO_2)	51.5
Moisture	.4
	99.2

It will at once be noticed that the lime content is too great to permit the use of the material in oxychloride cement. The freight is high from New Caledonia to Europe or America, so that the only exports have been a trial shipment of 42 tons in 1907.[b]

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[a] Glasser, Ed. M., Report à M. le ministre des colonies sur les richesses minérales de la Nouvelle-Calédonie: Ann. des mines, 10th ser., vol. 5, pt. 5, 1904, pp. 548–549.

[b] Eng. and Min. Jour., vol. 85, February 1, 1908, p. 283, quoting from Bulletin du Commerce, Noumea, New Caledonia.

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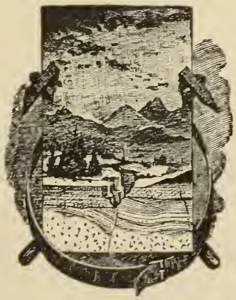
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 356

GEOLOGY
OF THE
GREAT FALLS COAL FIELD
MONTANA

BY

CASSIUS A. FISHER



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1909

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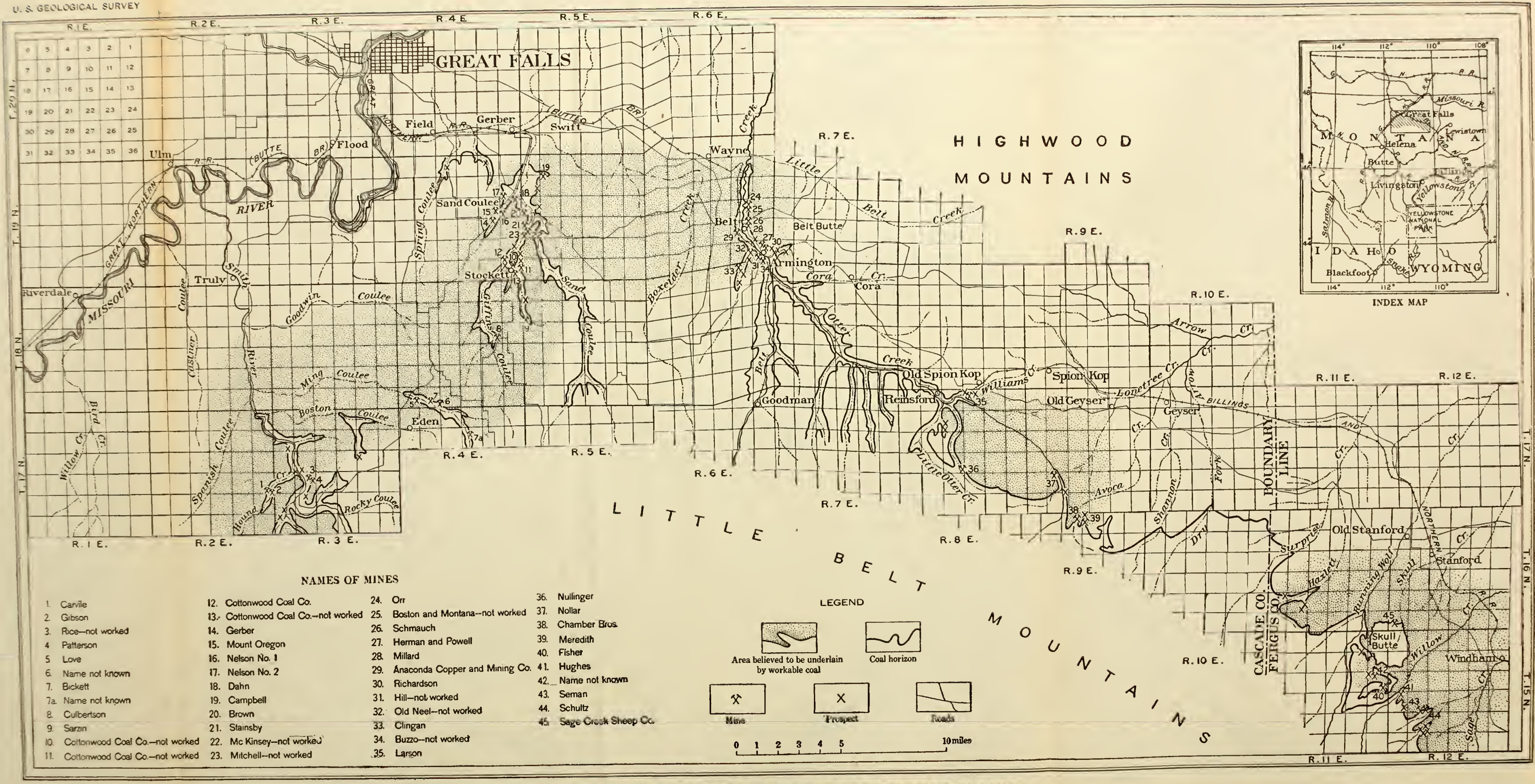
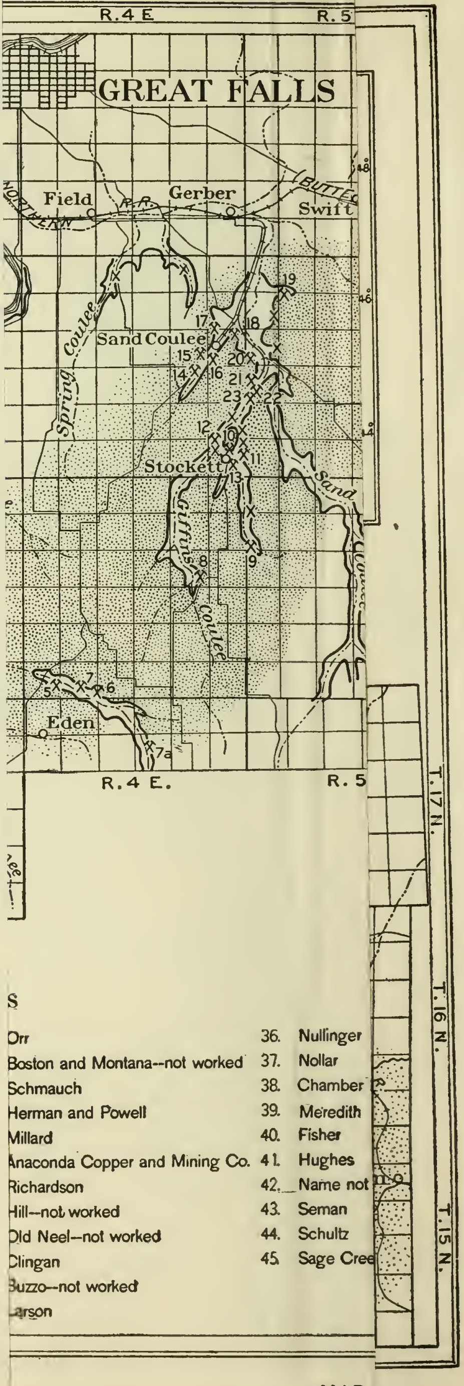


MAP OF THE GREAT FALLS REGION, MONTANA, SHOWING COAL LANDS.



S

Orr
Boston and Montana--not worked
Schmauch
Herman and Powell
Millard
Anaconda Copper and Mining Co.
Richardson
Hill--not worked
Old Neel--not worked
Clingan
Buzzo--not worked
Larson

36. Nullinger
37. Nollar
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39. Meredith
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MAP

GEOLOGY OF THE GREAT FALLS COAL FIELD, MONTANA.

By Cassius A. Fisher.

INTRODUCTION.

This report is the result of field studies made during the season of 1906. It is designed mainly to furnish information regarding the character and extent of the coal resources of the Great Falls region. It includes a description of the rock formations, indicating their character, distribution, structure, and stratigraphic relations, and also a brief statement of mineral resources other than coal.

The region under consideration comprises 1,500 square miles, situated mainly in north-central Montana, and extending along the base of the Rocky Mountain front range from a point 10 miles west of Judith River to a short distance beyond the Missouri. The location and orographic relations of the field are shown in the index map on Pl. I (in pocket). The field lies principally in Cascade County, but includes portions of Fergus and Chouteau counties, having as its boundary on the south the Big and Little Belt mountains and on the north the Great Plains and the Highwood Mountains.

Throughout the work the author was assisted by H. M. Eakin, who mapped portions of the area, measured many sections, and assisted in compiling the results for publication. Assistance in the field was also rendered by W. R. Calvert, J. D. Pollock, A. J. Hazlewood, and D. E. Winchester, and the author is indebted to S. B. Robbins, project engineer of the Sun River reclamation project, and to O. C. Mortson, formerly county surveyor of Cascade County, for valuable information placed at his disposal in connection with the preparation of the work.

LITERATURE.

The western half of the area here described as the Great Falls coal field has never been systematically studied by previous workers in geology, but several reports dealing with the general geology of different parts of the district to the east in the vicinity of the Highwood and Little Belt Mountains have been published.

The Great Falls of Missouri River, also the Giant Springs, are phenomena which have attracted widespread attention since the earliest explorers followed up the course of the Missouri to the northwest, and a number of descriptions of them have been published. Those appearing first set forth mainly the size and beauty of these falls, but later, as the region was settled and the town of Great Falls promised to become an important industrial center, a number of articles dealing with their utility were published in technical journals. Captain Lewis, of the Lewis and Clark expedition, which was made in 1804–1806, was the first to give an accurate account of the Great Falls and Giant Springs, and to describe certain features of the geography of the region bordering this portion of Missouri River. It is probable that other early explorers were attracted by the Great Falls and mentioned their occurrence and surroundings in describing the Northwest Territory.

The coals have been the subject of much of the geologic literature concerning this region, and many, if not most, of the more important geologic discoveries have been made in connection with a study of the nature and extent of these deposits. The investigations of the geologists of the Hayden and Transcontinental surveys in this part of the United States were confined mainly to the region lying east of Great Falls, and did not extend into the western part of the field. In 1880 W. M. Davis published an article[a] in which he gave an account of the geology of the Little Belt and Highwood mountains and the adjoining plains. During the same year George H. Eldridge described the geology of the Great Falls coal field. The next observer in the field was J. S. Newberry, who, in connection with an investigation of the surface geology of the country bordering the Northern Pacific Railroad, including the Great Falls coal field, discovered fossil plants associated with the coals, which established the Kootenai age of these deposits. After this discovery articles were published by Newberry and Fontaine dealing especially with the age of these coal-bearing rocks, as determined from their fossil floras, and their correlation with Kootenai rocks of other localities in the United States and Canada. In the spring of 1891 W. H. Weed, of the United States Geological Survey, while making a general study of the coal fields of Montana, visited this region and later described the coal deposits in considerable detail. The Geological Survey has published an annual account of coal operations in this field since 1888, and also a number of general reports on the coals of Montana and the Rocky Mountain region which have dealt principally with the production of this important coal field.

The first systematic work in this field was done in 1893–94 by W. H. Weed, assisted by L. V. Pirsson. In their published report[b]

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[a] Relation of the coal of Montana to the older rocks: Tenth Census U. S., vol. 15, 1880, pp. 697–712.

[b] Highwood Mountains of Montana: Bull. Geol. Soc. America, vol. 6, 1894–95, pp. 389–422.

the topographic and geologic features, structure, and characteristic rocks of the different eruptive centers of the Highwood Mountains and vicinity are discussed at considerable length. In 1899 the Fort Benton folio,[a] which includes the eastern part of the area described, and the Little Belt Mountains folio,[b] which treats of the area adjoining on the south, both by Mr. Weed, were published by the Geological Survey. During the past few years the glacial geology of this portion of Montana has been described by Warren Upham[c] and by F. H. H. Calhoun.[d]

Since the Government irrigation project has been undertaken in Sun and Teton valleys, a number of scientific and popular articles have appeared dealing principally with the surface waters of the district. In 1906 an investigation of the underground waters of this general region was made by the writer, the results of which will soon be published by the Geological Survey.

The following bibliography contains the titles of the more important geologic papers dealing with this region, arranged in chronologic order:

Lewis and Clark Expedition, 1804–1806 (Coues, 4 vols., 1893).

An account of the journey up the Missouri from St. Louis to the Rocky Mountains, thence to the Pacific coast. Contains description of the region bordering on the Missouri in the vicinity of Great Falls, Mont. The falls of the Missouri were measured and described; also brief mention made of the Giant Springs.

Hayden, F. V., Geologic report of the exploration of the Yellowstone and Missouri rivers, U. S. War Dept., pp. 85–94. 1860.

Contains a chapter on the geology from Wind River Mountains to Fort Union on Missouri River. Gives description of a trip down Smith River and past the falls of the Missouri to Fort Benton, etc. Includes geologic map of the area.

Williams, Albert, Jr., Mineral Resources U. S. for 1883–84: U. S. Geol. Survey, pp. 52–55. 1885.

The Montana coal fields are described briefly, and their area is estimated.

Newberry, J. S., Surface geology of the country bordering the Northern Pacific Railroad: Am. Jour. Sci., 3d ser., vol. 30, pp. 337–347. 1885.

Includes a brief description of the surface geology in the vicinity of Great Falls, Mont., with special reference to glacial drift.

Lindgren, Waldemar, Eruptive rocks: Tenth Census U. S., vol. 15, pp. 719–737. 1886.

The igneous intrusions of the Little Belt and Highwood mountains are described; also the dike near Sun River, including its character and mode of occurrence.

Davis, W. M., Relation of the coal of Montana to the older rocks: Tenth Census U. S., vol. 15, pp. 697–712. 1886.

Includes a description of the geology of the Little Belt and Highwood mountains and the plains region from Fort Benton up Missouri and Sun rivers.

Eldridge, G. H., Montana coal fields: Tenth Census U. S., vol. 15, pp. 742–751. 1886.

Treats of the coals along Belt Creek, Sand Coulee, and Deep Creek (Smith River), giving a section of the geologic formations at Belt Butte, near Belt. The coals of the Sage Creek area are described as a part of the Judith Basin coal fields.

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[a] Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899.

[b] Geologic Atlas U. S., folio 56, U. S. Geol. Survey, 1899.

[c] Outer glacial drift: Am. Geologist, vol. 34, 1904, pp. 151–160.

[d] Montana lobe of the Keewatin ice sheet: Prof. Paper, U. S. Geol. Survey No. 50, 1906.

Day, David T., Mineral Resources U. S. for 1885: U. S. Geol. Survey, pp. 36–39. 1886.

Brief reference is made to the coal production of the Belt and Sand Coulee mines.

Day, David T., Mineral Resources U. S. for 1886: U. S. Geol. Survey, pp. 262–288. 1887.

Eldridge is quoted in reference to the extent and character of Montana coal fields. (See Eldridge.) The production of the Great Falls region is given.

Newberry, J. S., The Great Falls coal field: School of Mines Quart., vol. 8, No. 4, p. 327. 1887.

Gives evidence as to the geologic age of the coal-bearing rocks in the Great Falls region, correlating them with the Kootenai formation of the Lower Cretaceous of Canada.

Chamberlin, T. C., Rock scorings of the great ice invasions: Seventh Ann. Rep. U. S. Geol. Survey, p. 77. 1888.

Discusses local "mountain wash" from Highwood Mountains, etc.

Mortson, O. C., and Ashburner, Chas. A., Mineral Resources U. S. for 1888: U. S. Geol. Survey, pp. 34–35, 289–292. 1890.

Describes the occurrence, extent, and chemical character of iron ores in the vicinity of Great Falls, Mont., pp. 34–35. Also refers to coal areas and operations in north-central Montana, pp. 289–292.

Swallow, G. C., Report of the Montana inspector of mines for the six months ending November 30, 1889, pp. 43–51.

Contains reports on various coal fields in Montana, including those of Cascade County. Analyses of Sand Coulee coal are given and comparison made with eastern coking coals. Estimates of the amount of coal in Cascade County are given.

Swallow, G. C., Report of the Montana inspector of mines, 1890.

Includes reports on various coal fields in Montana, making brief mention of those in Cascade County.

Newberry, J. S., Flora of the Great Falls coal field: Am. Jour. Sci., 3d ser., vol. 41, pp. 191–201. 1891.

Describes briefly the general geology of the Great Falls region, and gives detailed description of fossil plants collected near the mouth of Sun River, Montana.

Parker, E. W., Mineral Resources U. S. for 1889–90: U. S. Geol. Survey, pp. 228–231. 1892.

The coal product of Montana is treated by counties and the amount applied to various uses is also shown. List is given of producing mines of the Great Falls region. Sand Coulee mine is largest producer. Contains analysis of Sand Coulee coal.

Parker, E. W., Mineral Resources U. S. for 1891: U. S. Geol. Survey, pp. 269–270. 1893.

The production of Montana coal mines, including those in the Great Falls coal field, is referred to briefly.

Weed, W. H., The coal fields of Montana: Eng. and Min. Jour., vol. 53, pp. 520–522, 542–543, 1892; vol. 55, p. 197, 1893.

Describes the geologic occurrence of the coal beds and the character and extent of the coal deposits in various Montana areas, including Great Falls.

Shoemaker, C. S., Report of the Montana inspector of mines. 1893.

Includes reports on Cascade County coal mines. The equipment and output of Belt and Sand Coulee mines are treated on page 33, and they are described and a statement of their production given on page 86.

Weed, W. H., Two Montana coal fields: Bull. Geol. Soc. America, vol. 3, pp. 301–330. 1892. Abstract: Am. Geologist, vol. 11, pp. 181–182. 1893.

Describes the general geology of the Great Falls coal field, giving information concerning the character and extent of the coals. The age of the coal-bearing rocks is also discussed.

Wilson, H. M., American irrigation engineering: Thirteenth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 371–386. 1893.

The proposed irrigation system of the Sun River valley and the adjacent region is fully described, and the rainfall, topography, and amount of reclaimable land is discussed.

Parker, E. W., Mineral Resources U. S. for 1892: U. S. Geol. Survey, pp. 436–438. 1893.

The coal production of Montana is given by counties, and classified as to varieties—bituminous, semibituminous, and lignite.

Fontaine, W. M., Description of some fossil plants from the Great Falls coal field of Montana: Proc. U. S. Nat. Mus., vol. 15, pp. 487–495. 1893.

Gives a description of the general character of the flora, its age, and the characteristics of several new species.

Parker, E. W., Mineral Resources U. S. for 1893: U. S. Geol. Survey, pp. 320–322. 1894.

The coal output of Montana is given by counties. Reference is made to the increased activity over previous years.

Parker, M. S., Water power of the falls of the Missouri, Great Falls, Mont.: Eng. News, vol. 32, p. 44. 1894.

The several falls of the Missouri are described, and estimates made of their water power. Makes reference to the Giant Springs and their effect on the river water.

Weed, W. H., and Pirsson, L. V., Highwood Mountains of Montana: Bull. Geol. Soc. America, vol. 6, pp. 389–422. 1895.

Describes the topographic features, geologic structure, and characteristics of the rocks of each eruptive center of the Highwood Mountains. Reference is also made to the coal at Belt, Mont., its thickness, character, and age.

Parker, E. W., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 4, pp. 144–148. 1895.

The coals of Montana are discussed and reference is made to their geologic age. The bituminous and lignitic fields are differentiated. Production by counties is given.

Parker, M. S., The Great Falls water power: Eng. Rec., vol. 31, No. 16, pp. 274–275. 1895.

Gives brief description of the various falls of the Missouri near Great Falls, Mont., with illustrations of the power plant at Black Eagle Falls.

Shoemaker, C. S., Report of the Montana inspector of mines, 1895.

Includes reports of various coal fields in Montana, their production, etc. Cascade County mines are treated on p. 42.

Parker, E. W., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 454–458. 1896.

A condensed report on Montana coal production is included.

Parker, E. W., Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 5, pp. 551–556. 1897.

A review including the coal production of Montana by counties, from 1889 to 1896, inclusive.

Byrne, John, Report of the Montana inspector of mines, pp. 37–38. 1897.

Includes reports on coal fields of Montana, and describes Belt and Sand Coulee mines.

Parker, E. W., Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, pp. 456–461. 1898.

A brief review is given of production of coal in Montana, dating from 1889. The number of mines in each county (in 1896), their output, and various items of information regarding the production are included.

Parker, E. W., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6, pp. 440–443. 1899.

Cascade County is credited with two-thirds of the entire State coal production. Tables of coal production by counties are also included.

Weed, W. H., Fort Benton folio, Montana: Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899.

Describes the surface features, geology, structure, and history of the region. Treats in considerable detail the mineral resources, including coal, gold, and silver. Contains topographic, geologic, economic, and structural maps, also columnar sections.

Parker, E. W., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6, pp. 468–471. 1900.

Includes brief classified statistical tables of Montana coal production for 1898. States that a large proportion of coal is machine mined.

Byrne, John, Report of the Montana inspector of mines: Twelfth Annual Report, pp. 53–54. 1900.

Includes reference to workings and output of coal mines at Belt, Stockett, and Sand Coulee, Mont.

Parker, E. W., Mineral Resources U. S. for 1900: U. S. Geol. Survey, pp. 406–408. 1901.

Statistics are given of coal production in Montana for 1899. That of 1900 is stated to be the largest in the history of the State, amounting to 1,661,775 short tons; value $2,713,707. Sixty-three per cent of the total production was machine mined.

Storrs, L. S., The Rocky Mountain coal fields: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 415–471. 1902.

Includes discussion of the Montana coal fields, mentioning briefly the Great Falls coal field.

Parker, E. W., Mineral Resources U. S. for 1901: U. S. Geol. Survey, pp. 401–403. 1902.

Gives tables of Montana coal production. During 1901 the Sand Coulee mines were practically abandoned, decreasing the output of Cascade County 333,988 tons.

Storrs, L. S., Eighth Rept. Montana Bureau Agr., Labor, and Industry, pp. 374–382. 1902.

Coal statistics for the State are given, and Storrs is quoted in reference to the extent and distribution of Montana coal fields.

Willis, Bailey, Stratigraphy and structure, Lewis and Livingstone ranges, Montana: Geol. Soc. Am., vol. 13, pp. 305–352. 1902.

Describes the physiography, the occurrence, and character of the Algonkian, Carboniferous, Cretaceous, and Pleistocene formations, and the geologic structure of the general region.

Parker, E. W., Mineral Resources U. S. for 1902: U. S. Geol. Survey, pp. 396–398. 1903.

Tabulated statistics of Montana coal production are given.

Rowe, J. P., Some Montana coal fields: Am. Geologist, vol. 32, pp. 369–380. 1903.

Describes by counties the bituminous, semibituminous, and lignite coals of Montana, giving briefly their geologic age and distribution.

Rowe, J. P., Some volcanic ash beds in Montana: Bull. Montana Univ. No. 17 (geol. ser., No. 1). 1903.

Discusses the origin and physical and chemical properties of volcanic ash in Montana, describing by counties its characteristics, geologic position, and general distribution. A number of illustrations are introduced, showing the microscopic character of the volcanic ash, leaves found in the deposits, and thickness and character of beds.

Parker, E. W., Mineral Resources U. S. for 1903: U. S. Geol. Survey, pp. 484–487. 1904.

Contains brief review of coal-mining conditions in Montana as compared with previous years, and gives statistics of the coal output of the State.

Newell, F. H., Third Ann. Rept. U. S. Reclamation Service, pp. 307–313. 1904.

Discusses the proposed irrigation project of the Sun and Teton river district, and describes the water supply available from streams and storage reservoirs, also the territory which can be irrigated.

Leiberg, J. C., Forest conditions in the Little Belt Mountains Forest Reserve, Mont., and the Little Belt Mountains quadrangle: Prof. Paper U. S. Geol. Survey No. 30, 1904.

The surface waters of the region and their relation to agricultural, grazing, and forest lands are included in the discussion.

Stockett, Lewis, A bituminous coal breaker in Montana: Min. World, vol. 20, March 26, 1904.

Gives section and analysis of the coal bed mined at Stockett, Mont., and a detailed description of the coal breaker used by the company.

Upham, Warren, Outer glacial drift: Am. Geologist, vol. 34, pp. 151–160. 1904.

Discusses the glacial drift of the northwestern States, including Montana. Reference is made to the effect which the glaciation had on the course of Missouri River.

Parker, E. W., Mineral Resources U. S. for 1904: U. S. Geol. Survey, pp. 512–515. 1905.

Includes a discussion of the various Montana coal fields, their geologic age and importance. The production by counties is given, and the State output tabulated from 1880, the year of first reported production.

Savage, H. N., Fourth Ann. Rept. U. S. Reclamation Service, pp. 222–224. 1905.

Includes report of surveys and lands to be irrigated by the Sun River project.

Pirsson, L. V., Petrographic province of central Montana: Am. Jour. Sci., 4th ser., vol. 20, pp. 35–49. 1905.

Treats of the various igneous occurrences in the region of Belt and Highwood mountains, including a description of the porphyry of the Wolf Butte and Square Butte (of Highwood Mountains) laccoliths, and dike near the Highwoods on Williams Creek.

Rowe, J. P., Montana gypsum deposits: Am. Geologist, vol. 35, pp. 104–113. 1905.

The gypsum deposits are classified by localities, as the north, middle, and south fields. The middle field includes Cascade and Fergus counties. Includes description of Stucco mill on Belt Creek, giving location and age of deposits.

Rowe, J. P., The Montana coal fields: Min. Mag., vol. 11, pp. 241–250. 1905.

Discusses the production and value of coal from various fields in Montana, including the Great Falls coal field. Treats of present and future development of Belt and Sand Coulee mining districts, including geologic distribution of Montana coals by counties. Boiler tests and chemical analysis of Belt coal are also given.

Parker, E. W., Mineral Resources U. S. for 1905: U. S. Geol. Survey, pp. 631–633. 1906.

Statistics are given of the Montana coal output, also a short discussion of the different fields.

Walsh, William, Report of the Montana inspector of mines, pp. 29–38. 1906.

Includes reports of Cascade County mines, their development, production, etc.

Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906.

Describes briefly the surface features and geology along the terminal moraine of the Keewatin ice sheet in Montana. Contains detailed description of the glacial deposits and discusses the effects of glaciation of the region on the course of Missouri River.

Rowe, J. P., Montana coal and lignite deposits: Bull. Montana Univ. No. 37 (geol. ser. No. 2). 1906.

Describes Montana coals by counties. Contains a bibliography of literature bearing on the subject.

Fisher, C. A., Great Falls coal field: Bull. U. S. Geol. Survey No. 316. 1907.

Describes briefly the coals of the Great Falls region, giving their location, topographic relation, and geologic occurrence. Detailed description of the deposit is given and representative sections introduced. The present development of the various basins within the field is treated, and the quality of the coal is briefly described, including a number of ultimate analyses of representative coals in the field.

Fisher, C. A., Southern extension of the Kootenai and Montana coal-bearing formations in northern Montana: Econ. Geol., vol. 3, pp. 77–99. 1908.

Describes the Kootenai formation in the vicinity of Great Falls, Mont., tracing it southward across the Montana-Wyoming State line into the Bighorn basin, where it is correlated with the Cloverly formation. The subdivisions of the Montana group in northern Montana, as first worked out by Stanton and Hatcher, are also traced southward to the State line. The occurrence of coal in these formations at different localities throughout the area treated is given.

Fisher, C. A., Geology and water resources of the Great Falls region, Montana: Water Supply Paper No. 221, U. S. Geol. Survey, 1908.

A brief treatment of the general geology of the region is given, with special reference to the prospects for the occurrence of underground water. The surface waters are also described, including their present and proposed uses for irrigation, waterpower, etc.

TOPOGRAPHY.

RELIEF.

The area treated in this report presents a considerable variety of geographic features, all of which have a direct or indirect bearing on the development of the coal resources of the Great Falls field. The area lies within a zone which is transitional between plains and mountain topography, including portions that present features characteristic of both provinces. Its salient features are broad, gently sloping plateaus bordering the adjacent mountain ranges. These plateaus are traversed by numerous mountain streams, which flow through valleys that are deep and relatively narrow in the central portion of the district, but that become wide and open on the plains to both the east and the west. Along the southern margin of the area, from Smith River to the eastern end of the field, the surface of the plains rises gradually by sloping plateaus, culminating in a zone of high, hilly country bordering the Little Belt Mountains, which lie to the southward. East of Belt Creek and north of the area described the Highwood Mountains, a cluster of isolated peaks, rise abruptly above the plains to an altitude of 6,700 feet. Between the Highwood and Little Belt mountains there is a divide locally known as the Otter Creek divide, whose altitude at its lowest point is about 4,500 feet. The country east of this divide is drained by Arrow Creek and its tributaries; that to the west by Belt Creek and its largest affluent, Otter Creek, from which the divide derives its name.

The range of altitude within the field is moderate. The highest points occur along the base of the Little Belt Mountains, where the more prominent summits rise to an altitude of about 5,500 feet, while the lowest portion of the field lies along Missouri River, below Big Falls, where the altitude is about 3,000 feet above sea level. The average altitude of the region is between 3,500 and 4,000 feet, and the extreme variation in altitude for any given locality is about 1,300 feet in a horizontal distance of 1½ miles. This difference in elevation occurs between Belt Creek and the summit of Belt Butte.

In the plains province the relative altitudes of the valley bottoms and the summits of the bordering plateaus range from 300 to 600 feet.

East of the low divide between the Highwood and Little Belt mountains the country slopes gradually northeastward toward Missouri River. It is traversed by several streams draining the northeastern slope of Little Belt Mountains. These streams flow through relatively wide open valleys bordered by gravel-capped terraces of different elevation. Stanford Butte, a prominent ridge between Running Wolf and Surprise creeks, is capped by a remnant of an ancient terrace, and to the north and east of this ridge gravel-capped plateaus at lower levels occupy all the interstream spaces. Toward the Little Belt Mountains the gravel-capped terraces give way to prominent hogback ridges formed by the sandstone members of the Ellis and Kootenai formations, which extend in an irregular line along the base of the mountains. Skull Butte, a low dome-shaped uplift about 6 miles south of Stanford, rises nearly 200 feet above the surrounding region. It is considerably dissected about the periphery and in the center by numerous small streams, some of which expose the coal bed of the Kootenai formation, which encircles this uplift. South of Skull Butte there are a number of prominent ridges with long gradual slopes to the north and bold escarpments to the south, overlooking valleys which have been excavated in the softer shale of the Quadrant formation.

Throughout the area east of the low divide connecting the Highwood and Little Belt mountains the valleys leading into the mountains are wide and open on the plains, but toward the foothill zone they decrease in width, deepen, and branch into many canyon tributaries which cut the upturned edges of the coal-bearing Kootenai rocks, thus exposing the coal bed at many places. These numerous small valleys lead from the zone of coal outcrop in the higher hogback ridges down to the more nearly level plains region where the main line of the Billings and Northern Railroad has been constructed, and thus afford an easy approach to the coal.

Broadly viewed, the country between Otter Creek divide and Missouri River, which includes the largest area in the Great Falls coal field underlain by workable coal, is a high plateau sloping gently northward, and deeply dissected by numerous canyons. Otter, Belt, and Boxelder creeks, Sand Coulee, and Smith River are the principal streams traversing this area. All of these except Boxelder Creek flow through deep, narrow valleys which cut through and expose the coal, and along them, owing to the general accessibility of the beds, the principal development of the coal resources of the Sand Coulee area has taken place. The altitude of the plateau varies from 3,500 feet along Missouri River to 4,500 feet or more along the southern border of the area. The difference in altitude between valley bottom and plateau summit in the northern part of the district is 200 to 400 feet, but toward the mountains this difference increases to over 600 feet. The streams of this district all flow in a northerly direction except three of the larger tributaries of Smith River—Boston, Ming, and Goodwin coulees—which flow nearly west. Sand Coulee, which is formed by the confluence of a number of canyon tributaries 6 miles southeast of Stockett, continues northward for several miles to a point when it turns sharply to the west, and for the remainder of its course it meanders through a wide, flat-bottomed valley formed by the preglacial erosion of Missouri River.

West of the Missouri and south of Sun River the surface rises in successive plateaus to the west. The lowest of these, which lies north of Ulm station and comprises what is locally known as Ulm Bench, has an altitude of about 3,650 feet. On the west side of Ulm Bench there is a low saddle separating it from a higher plateau, only a small portion of which is included within the area described. North of Sun and Missouri rivers there is a high plateau region which farther west is deeply dissected by the valley of Muddy Creek. East of Muddy Creek only the southern edge of this plateau is included within the field. It extends eastward as a line of prominent bluffs north of Great Falls, terminating in a group of ridges and buttes of which Black Butte is a conspicuous outlier.

DRAINAGE.

The Great Falls field, being located along the base of the Rocky Mountain front range, is traversed, especially in its western half, by a number of relatively large mountain streams, some of which have been important factors in the industrial development of the district. The eastern half of the area contains no large rivers, but is drained, as previously stated, by numerous small mountain streams which flow northeastward, entering the Missouri by way of Judith River.

MISSOURI RIVER.

The principal stream of the district is Missouri River. It enters the field near Cascade, and flows in a northerly direction to the vicinity of Great Falls, where it pursues a more easterly course, continuing thus to the border of the field. The portion of the stream above Great Falls flows in a meandering course through a wide, open valley, but that below this point occupies a narrow valley bordered by precipitous bluffs, passing over a number of cataracts known as the Great Falls of Missouri River. At present only one of these falls, Black Eagle, the uppermost of the series, is utilized for the development of power. The drainage area of the Missouri at Cascade, Mont., is estimated as 18,295 square miles, and the flow of the river ranges from 2,000 to 22,000 second-feet. Its largest tributaries from the south are Smith River and Belt Creek, and from the west Sun River. A number of medium and large-sized intermittent streams with relatively large drainage areas enter the river from either side. Bird Creek, Castner Coulee, Sand Coulee and its tributaries, Boxelder Creek, and Red Coulee enter from the south, and Little Muddy Creek enters from the west. The city of Great Falls and the Boston and Montana smelters are located on Missouri River, and the Great Northern Railway has been built up its valley through the Big Belt Mountains, connecting Great Falls with the large mining centers of Butte and Anaconda.

SUN RIVER.

Sun River rises high in the Lewis Range and joins the Missouri at Great Falls. Only the lower course of the river, however, is included within this field. The main stream is formed by the union of the north and south forks of Sun River, which occurs about 3 miles below Augusta, a town located a few miles east of the base of the Lewis Range, beyond the limits of the field. The principal tributary of Sun River from the north within the area described is Muddy Creek, which drains the high plateau between Sun and Teton rivers, emptying into the latter near Vaughn. It is an intermittent stream of minor importance.

SMITH RIVER.

Smith River has its source far to the southeast, in the vicinity of Castle Mountains, and flows northwest, draining the highland between the Big and Little Belt mountains. It enters the area described near the center of the south line of T. 17 N., R. 3 E., and, flowing in a northeasterly direction, joins Missouri River at a point near Ulm. Within the district the stream flows in a meandering course through a deep and moderately narrow valley, which exposes high in its bluffs on either side the workable coal bed of the Kootenai formation throughout Tps. 17 N., Rs. 2 and 3 E. Smith River has a flow ranging from about 50 to over 400 second-feet; its largest tributary is Hound Creek, which joins it from the west near Orr post-office. The valley of Hound Creek also exposes the workable coal of the lower part of the Kootenai for about 1 mile above its mouth, and the largest mine in the Smith River district is located on this tributary, in the SW. ¼ sec. 24, T. 17 N., R. 2 E. Hound Creek, a vigorous mountain stream having a continuous flow, drains the northern end of the Big Belt Mountains, some of its tributaries extending far up the slopes of that range. From the east three intermittent streams enter Smith River—Boston, Ming, and Goodwin coulees. In the upper part of Ming Coulee, in the vicinity of Eden, the valley exposes the coal measures, and here a number of small mines have been opened. The same is true in the upper part of Boston Coulee. Smith River Valley and its principal tributaries, Ming and Boston coulees and Hound Creek, furnish a valuable means of access to the coals of this little-developed portion of the Great Falls coal field. The large flow of water in Smith River is also an important consideration in the development of this coal district, for the percentage of impurities present in the coal is sufficient to render washing necessary before it can be successfully placed on the market. In neither Boston nor in Ming coulee is there sufficient water to wash the coals that could be mined from them, but the impurities might be removed by a dry-washer process such as is now employed at Stockett.

BELT CREEK.

Belt Creek rises in the northern part of the Little Belt Mountains, flows northward across the central part of the district, draining the territory west of the Highwood Mountains, and enters the Missouri about 12 miles northeast of Great Falls. It flows through a valley about 300 feet deep, which has a width varying from one-half to three-fourths of a mile. In the vicinity of the town of Belt, where the valley crosses the area underlain by coal, it exposes in the bluffs on either side, a short distance above the valley, beds of coal of workable thickness, thus producing favorable conditions for the development of the deposits. A number of mines are located there, including the Anaconda Copper Mining Company's mine, one of the largest in the Great Falls coal field.

Belt Creek is a vigorous mountain stream which carries a large flow of water throughout all seasons of the year, especially in its upper course, but at the town of Belt all this water sinks to an underflow during the late summer months, leaving the stream bed dry. This loss is due principally to the fact that the valley floor here consists of soft, porous sandstones, into which the water passes readily. From a point a short distance below the town of Belt to its mouth the stream has a small but continuous flow. A view of the dry bed at Belt is shown in Pl. III. The sinking of the flow of Belt Creek at Belt is a disadvantageous feature from a coal-mining point of view, for it renders it necessary to sink wells in the valley in order to obtain a sufficient amount of water to wash the impurities from the coal.

The principal tributaries of Belt Creek are Otter Creek from the east and Neel Creek from the west. Otter Creek rises on the northern slope of Little Belt Mountains, and, flowing northwest, enters Belt Creek about 1 mile above Armington. It carries considerable water derived from snow on the mountains and from springs along its course. Neel Creek is a much smaller stream, having an intermittent flow. In the lower part of the valley of Neel Creek coal of

DRY BED OF BELT CREEK, NEAR BELT, MONT.

workable thickness is exposed. That part of Otter Creek Valley which lies between Spion Kop and Nollar's mine crosses an area underlain by valuable coal deposits, but in the center of this area the valley is not cut sufficiently deep to expose the coal, which, however, could be easily reached by shafting. The favorable location of this valley with respect to the limits of the coal area offers a valuable means of access to the deposits.

OTHER SMALL STREAMS.

The area between Belt Creek and Smith River is drained by Boxelder Creek and Sand Coulee. Boxelder Creek rises high on the plateaus about 3 miles west of Riceville, flows northward in a direction roughly parallel to Belt Creek, and enters the Missouri about 9 miles east of Great Falls. It carries only a small flow of water, and its valley in the upper part, where coal-bearing rocks occur, is not cut sufficiently deep to expose the coal; hence it is not an important factor in the development of this part of the Great Falls coal field. Sand Coulee, an intermittent stream with a large drainage area, is formed by the union of several small canyon tributaries southeast of Stockett. It continues northward to a point about 6 miles below Stockett, where it makes a sharp turn to the west and meanders through a wide, level-floored valley for about 7 miles, entering Missouri River about 4 miles above Great Falls. This intermittent drainageway, especially in its upper course, and its tributaries from the west, Straight and Giffen coulees, have deep narrow valleys, which cut and expose the coal-bearing zone of the Kootenai formation, thus producing favorable conditions for development. It is in the valleys of these intermittent streams, where the towns of Stockett and Sand Coulee are located, that the greatest coal mining activity has taken place.

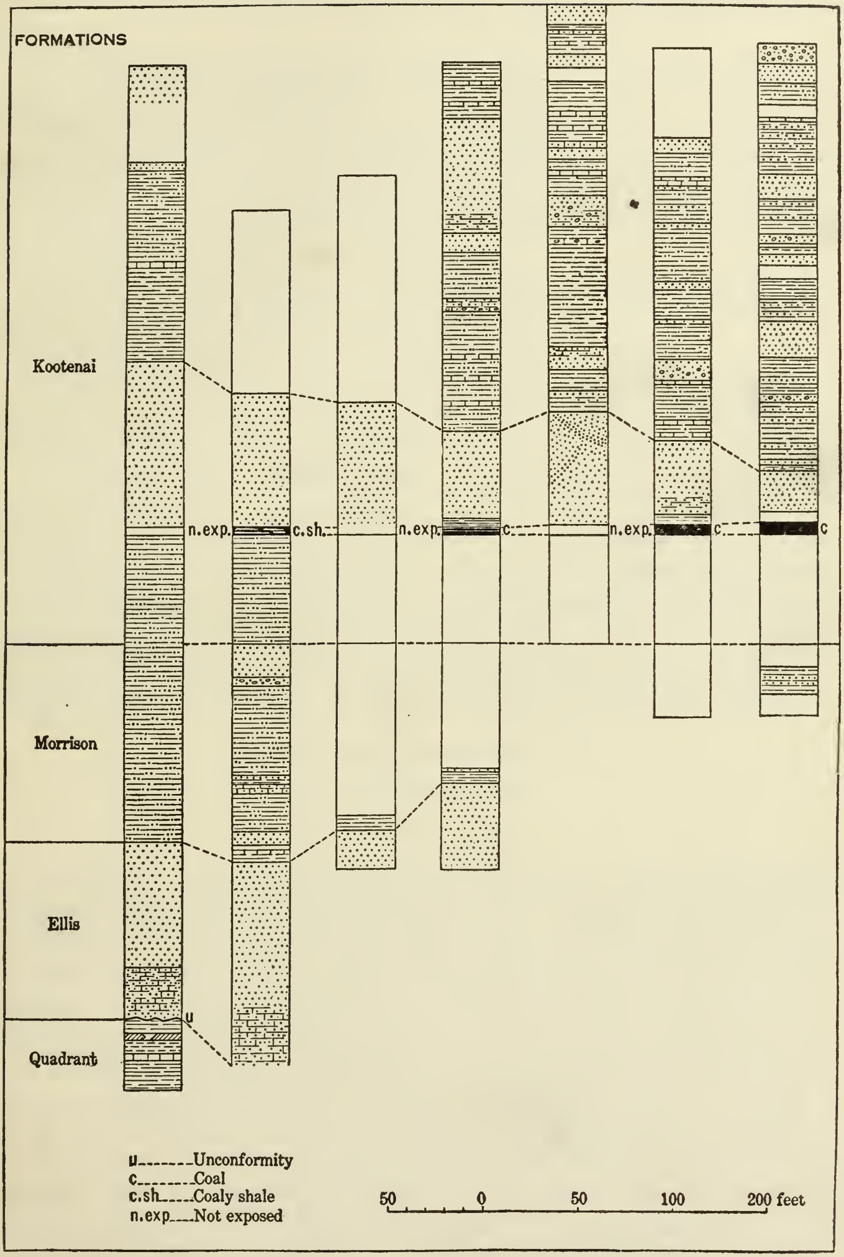
East of Otter Creek there is a prominent ridge that forms a low divide between Highwood and Little Belt Mountains. The drainage to the east of this divide, as previously stated, is all to the northeast, into Arrow Creek, a small tributary of the Missouri entering the latter a short distance above the mouth of Judith River. Arrow Creek, which has its source on the southern slope of Highwood Mountains, flows eastward, passing out of this district in T. 18 N., R. 11 E. Its principal affluents are Surprise and Running Wolf creeks, the former having its source at the base of Wolf Butte and pursuing a northeasterly course. Running Wolf Creek rises higher up the slopes of the Little Belt Mountains farther to the southeast, and flows northeastward past Stanford Butte. East of Running Wolf Creek several small branches cross the extreme southeast corner of the district and enter Judith River. These are Skull, Willow, and Sage creeks, all of which, as previously stated, expose in their upper courses workable beds of coal.

CULTURE.

Settlement in the Great Falls field, as elsewhere, is determined by geologic and climatic conditions. Along all the larger stream valleys where surface water for irrigation purposes is available settlements are numerous, while much of the upland and grazing districts is thinly populated. On the higher slopes bordering the mountains in the zone of increased rainfall there are many small farms, some of which are among the best improved places in the district.

There is one relatively large town, three medium-sized coal-mining towns, and a number of smaller trading points. Great Falls, a town of 18,000 inhabitants and a thriving business center, is located on Missouri River near the north-central portion of the field. While at present none of its railroad lines are transcontinental, they are the most important connecting lines between the Great Northern and the Northern Pacific, and when the Billings and Northern is completed it will open up a new transcontinental route through Great Falls to the northwest coast. At the present time railroads extend in four directions from Great Falls—one southwest to Helena and Butte; another northwest to Havre, a small town on the main line of the Great Northern; a third, the Montana and Great Northern, northwest to Shelby Junction; and a fourth, the Neihart branch of the same road, southeast to Neihart. The last named is connected with Stockett and Sand Coulee, two of the larger coal-mining camps, by a short branch line from Gerber station. The Boston and Montana Consolidated Copper and Silver Mining Company's smelters and refineries are located at Great Falls, as is also the Royal Milling Company's plant and a number of smaller business enterprises. The ore handled at the smelters comes from Butte and Anaconda; this, together with the coal and limestone used in the operation of the plant makes a relatively large freight traffic for Great Falls, while it also furnishes employment for a large number of men.

Belt, one of the largest coal mining towns in the district, has a population of about 1,000, composed mainly of employees of the Anaconda Copper Mining Company, the largest coal-mine operator at the place. It is located on Belt Creek, about 25 miles southeast of Great Falls, on the Neihart branch of the Great Northern Railway, and is the oldest coaling town in this region. About 10 miles southwest of Belt and nearly 20 miles from Great Falls are the two coal-mining towns of Stockett and Sand Coulee. Stockett, which has a population of about 800, composed largely of coal miners employed by the Cottonwood Coal Company, one of the two largest coal mining companies operating in the district, is located on East Fork of Sand Coulee. Sand Coulee, about 2½ miles northwest of Stockett, is a smaller mining town of about 400 people. It is situated in Cottonwood Coulee, a branch of Sand Coulee, and owes its existence mainly



COLUMNAR SECTIONS OF THE STRATIGRAPHY ALONG BELT CREEK VALLEY.

(Columns are numbered from left to right.)

1, West side of Belt Creek, 1 mile north of Goodman siding; 2, east side of Belt Creek, 2½ miles north of Goodman siding; 3, west side of Belt Creek, one-eighth mile above mouth of Otter Creek; 4, east side of Belt Creek, one-eighth mile below mouth of Otter Creek; 5, east side of Belt Creek, one-half mile above Belt; 6, east side of Belt Creek at Belt; 7, west side of Belt Creek at Belt.

to the Nelson and Gerber coal companies, which are operating at this place.

The remainder of the towns within the district are supported mainly by a ranch population.

There are no towns along Missouri River below Great Falls within the area described, but above that town there are two small stations, Ulm and Cascade. The latter, located near the base of the Big Belt Mountains, has a population of about 200, and is supported by a large ranch trade along either side of the river.

About 2 miles above the mouth of Smith River there is a post-office known as Truly, and farther up the river there was another known as Orr, which has recently been discontinued.

In Belt Creek Valley, about 2 miles above Belt, is the small town of Armington, which is situated at the junction of the Billings and Northern Railroad and the Neihart branch of the Great Northern. It is mainly a small railroad town, which receives a portion of the ranch trade of the surrounding country. Along the Billings and Northern Railroad there are a number of new towns and sidings, located at intervals of about 6 miles. These are Reinsford, Spion Kop, Geyser, Stanford, and Windham. Old Stanford and Old Geyser, which are located at some little distance from the new town sites bearing these names, are important trading points for a large ranch district along Arrow, Skull, Running Wolf, and Sage Creek valleys.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

GENERAL OUTLINE.

The surface formations throughout the area to which this report relates consist mainly of sedimentary rocks and igneous intrusives in the form of dikes and laccoliths, the intrusives being especially abundant throughout that part of the field bordering the adjacent mountain ranges. The strata lie in general nearly horizontal, dipping at a relatively small angle to the north and east, away from the mountains and toward the plains. Throughout most of the Great Falls field the rocks lie apparently flat, but on closer examination they are found to be gently folded into a series of shallow synclines and low anticlines. These, however, are scarcely perceptible to the casual observer, being revealed only by careful examination of the beds exposed along the sides of some of the valleys. The rocks are representative of Carboniferous, Jurassic, Cretaceous, Tertiary, and Quaternary systems. The distribution of the formations is shown on the geologic map (Pl. I), and their stratigraphy and structural relations are illustrated in the columnar and cross sections shown on Pl. IV and Pl. VII. The table on pages 22–23 shows the age, order, characteristic features, thickness, distribution, stratigraphic relations, and economic importance of the formations.

Geologic formations in the Great Falls region.

System.	Formation.	Character of deposit.	Thickness (feet).	Areal distribution.	Relation to other formations.	Economic importance.
Quaternary.	Alluvium.	Light-colored silt and clay, with local gravel beds.	20 to 40	Occupies valleys throughout the district.	Lies unconformably upon older formations.	Contains sand and gravel for masonry and clay for brick.
	Lacustrine deposits.	Fine-grained, light-colored silt and clay.	Not determined.	Occurs as a valley filling in all the larger valleys in front of the terminal moraine.	Lies unconformably on older rocks.	Clay suitable for the manufacture of building brick.
	Morainal deposits.	Unassorted mixture of sand and gravel in which bowlders of varying size are scattered but not abundant.	Not determined.	Occupies area lying south of Missouri River between Great Falls and Belt Creek; also a narrow strip north of Missouri River in the vicinity of Great Falls.	Occurs as a thin mantle on the plateaus of Cretaceous rocks and as a filling in preglacial valleys.	Contains local beds of gravel suitable for road construction, also some common varieties of clay.
Quaternary and tertiary (?).	Terrace gravel.[a]	Sand, gravel, sandy clay, and conglomerate.	25 to 40.	Principal areas lie east of Otter Creek divide.	Lies unconformably on older rocks.	Gravel suitable for general masonry.
Cretaceous.	Colorado shale.	Upper part consists of dark-colored shale with a few thin sandstone layers and a bed of volcanic ash; lower part consists of massive gray sandstone, often concretionary, iron-stained, and containing thin layers of pebbly conglomerate.	1,600.	Exposed along southern side of Highwood Mountains from Belt Creek to eastern border of district. Basal sandstones of formation cap the plateau region between Red Buttes and Missouri River; also the area between Missouri and Sun rivers; and occur north of Sun River.	Lies apparently conformably upon Kootenai rocks.	Contains sandstone suitable for building purposes; also valuable clay, bentonite, volcanic ash, etc.
	Hiatus.					
	Kootenai formation.	Massive gray sandstone, red sandy shale and clay, with an occasional bed of white limestone. The sandstone predominates in the lower portion while the red shale, clay, and limestone constitute the greater part of the upper members; bed of workable coal about 60 feet above base.	400 to 500.	Occupies surface area over a great part of the district lying between Smith River and Belt Creek and is the surface formation of high plateaus south of Otter Creek; east of Otter Creek extends as a narrow outcrop along northern side of Little Belt Mountains.	Lies apparently conformably on Morrison formation.	Valuable deposits of coal and fire clay occur in the lower part of formation, and the basal sandstones are used successfully as building stone.

Jurassic (?).	Morrison shale (?).	Variegated shale and clay, containing sandstone layers, one above the middle of the formation; cinnamon-brown color; bone-bearing; limestone layers sometimes present in lower part.	80 to 120.	Outcrops as a narrow band below Kootenai rocks in sides of canyons bordering streams draining northern slope of Little and Big Belt Mountains from Smith River to Otter Creek. East of Otter Creek its outcrop zone, which is of varying width, generally occupies an inner face of low hogback ridges of Kootenai rock bordering the Little Belt Range.	Lies apparently conformably on Ellis formation.	Contains limestone and clay.
Jurassic.	Ellis formation.	Dove-colored limestone, overlain by reddish-brown, coarse-grained sandstone, coarsely conglomeratic at base.	80 to 120.	Between Smith River and Otter Creek; the outcrop area is limited to canyons traversing the plateau region bordering the Little and Big Belt Mountains.	Lies unconformably upon Quadrant and Madison formations.	Sandstone and limestone could be used for building purposes.
	Unconformity.					
Carboniferous.	Quadrant formation.	Sandstone, red and green shales, clays, and limestone, with an occasional bed of gypsum in lower part; also one at the top.	350 to 500.	In the upper part of Belt Creek Valley and extending eastward throughout a zone of varying width along the base of the Little Belt Mountains to the east end of district.	Lies apparently conformably upon Madison limestone, but there is a very abrupt change in character of rocks along the contact.	Gypsum occurs in deposits of workable thickness in lower part of the formation, and also at the top.
	Madison limestone.	Massive, light-gray limestone and argillaceous shale.	140 exposed.	In Smith River Valley in T. 17 N. R. 3 E., in the vicinity of Stockett, along the northern base of Little Belt Mountains from Belt Creek to east end of district.		Limestone is used extensively in the Boston and Montana smelters at Great Falls for fluxing.

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[a] The highest gravel terraces are probably of late Tertiary age.

SEDIMENTARY ROCKS.

CARBONIFEROUS SYSTEM.

MADISON LIMESTONE.

General statement.—The Madison limestone is very conspicuous along the north side of the Little Belt Mountains, but the greater part of it lies outside of the area here described. The only exposures in the district are along East Fork of Sand Coulee and its tributaries and on Smith River, where a local doming of the beds exposes 100 to 200 feet of the formation. Its distribution is shown on the geologic map (Pl. I). Along the flanks of the Little Belt Mountains outside of the area to which this report relates the limestone has a thickness of about 1,000 feet and consists of three members. The lowest member, which is more or less argillaceous, has been called the Paine shale, the more massive limestone of the middle part the Woodhurst limestone, and the top member the "Castle" limestone. In the Little Belt Mountains the Madison limestone carries a typical Mississippian fauna.

"Castle" limestone member.—The "Castle" limestone member, which forms "Sluicebox Canyon," the lower end of which is at Riceville (Pl. V), is exposed to view at numerous places in the vicinity of Stockett; farther south, in the head of Ming Coulee; and on Smith River. Within the area examined its greatest observed thickness is about 140 feet, which is found at the head of Ming Coulee, about 10 miles southwest of Stockett. Here the rock is massive, compact, and of a medium-gray color, but weathers light. It occurs in strata 15 to 20 feet thick, which at many places have weathered to rough, cavernous surfaces, forming castellated masses. Interbedded with the massive strata are thin layers of softer calcareous material. At Stockett 15 feet of oolitic limestone was observed in this formation, underlain by compact light-colored limestone. The fossils listed below were collected from the limestone at Stockett and at the head of Ming Coulee, outside of the area described:

Fossils from Stockett, Mont.

Amplexus sp.
Zaphrentis sp.
Syringopora surcularia.
Schuchertella sp.
Spirifer centronatus var.
Spiriferina solidirostris.
Seminula madisonensis.
Seminula humilis.
Cleiothyridina crassicardinalis.
Eumetria verneuiliana.

Fossils from head of Ming Coulee.

Schuchertella sp.
Spiriferina solidirostris.
Seminula madisonensis.
Eumetria verneuiliana.
Camarotœchia sp.

MADISON LIMESTONE OVERLAIN BY QUADRANT SHALE, NEAR RICEVILLE, MONT.

These fossils were determined by George H. Girty, who regards them as Mississippian in age.

The Madison limestone in the vicinity of Riceville is overlain by the brick-red sandy shale or impure sandstone of the Quadrant formation, but farther west, in Sand Coulee and its tributaries, and also at the head of Ming Coulee and on Smith River, the Quadrant is absent, the basal limestone or the calcareous conglomeratic sandstone of the Ellis formation resting upon the Madison limestone. These unconformable relations are shown in cross section C–C, Pl. I, and on Pl. VI.

QUADRANT FORMATION.

Character and extent.—The Quadrant formation comprises a succession of beds of variable character and thickness which immediately overlie the Madison limestone in most places throughout the Little Belt Mountains region. These beds, although different in character, have been regarded by Weed as the stratigraphic equivalent of the Quadrant formation near Quadrant Mountain in the Yellowstone Park region, where the name was first applied. The Quadrant formation in the Great Falls field consists of sandy shale or argillaceous sandstone and limestone with beds of gypsum in the lower part and near the top. It is not coal bearing, and consequently is not included in the area studied except at a few localities, notably on Belt Creek near Riceville, on Little Otter Creek 2½ miles above its mouth, along the base of Little Belt Mountains from Geyser Creek to near the southeast corner of the area described, and in the central part of Skull Butte. No careful study was made of the stratigraphy of the formation except on Belt Creek near Riceville, where the basal member consists mainly of red and green sandy shale with an occasional bed of white gypsum and a few thin layers of white limestone. Very few typical sandstone members were observed at this locality, although Weed [a] has applied the name Kibbey sandstone to the basal member of the Quadrant in this general region. The upper member of the section, which the same writer has designated the Otter shale, consists largely of red and green sandy shale with limestone layers occurring at frequent intervals. No gypsum was observed in this part of the section except near the top. The following section of a part of the formation was measured near Riceville:

Section of part of Quadrant formation on east side of Belt Creek near Riceville, Mont.

	Ft.	in.
Shale, dark green	51	
Limestone, white	1	
Shale, green, sandy	1	

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[a] Weed, W. H., Description of the Fort Benton district: Geologic Altas U. S., folio 55, U. S. Geol. Survey, 1899.

Section of part of Quadrant formation on east side of Belt Creek near Riceville, Mont.—Continued.

	Ft.	in.
Limestone, white, compact, laminated	2	6
Shale, dark greenish	20	
Shale, greenish, sandy	20	
Limestone, dove-colored, thinly laminated	1	
Shale, red and green, containing hard limestone layers 68 inches thick	25	
Limestone, alternating layers of, and shale, greenish	7	
Shale, red, containing layers of dove-colored limestone in lower part	14	
Limestone, blue, compact, porous	3	
Limestone and shale, gray, alternating layers of white and dove-colored limestone thinly laminated, with an occasional bed of gray shale	20	
Soft sandy material	11	
Limestone, hard, gray, compact	3	6
Shale, dark green, sandy	20	
Limestone, hard, gray, compact	1	6
Soft sandy material	8	6
Gypsum, white	3	6
Gypsum, impure, and dark-gray shale, with nodules of black flint	6	
Shale, greenish, sandy, containing thin layers of white limestone	34	
Limestone, white		6
Shale, green, sandy	6	
Limestone, white		8
Shale, green, sandy	29	
Limestone, white, compact	2	
Gypsum, white	2	
Shales, red and green, sandy	34	6
Beds concealed	7	
Shale, red	17	
Madison limestone.		
Total	352	2

The total thickness of the formation as observed near Riceville is less than 500 feet, but according to Weed[a] its thickness greatly increases toward the southeast, reaching a total of 1,400 feet near Utica. Farther east, along the Little Belt and Big Snowy mountains, W. R. Calvert[b] has observed that the Quadrant has a thickness varying from 450 to 750 feet, while its lithologic character is not materially different from that shown on Belt Creek, except for the absence of beds of gypsum.

The Quadrant formation is overlain unconformably by the basal limestone and conglomeratic sandstone of the Ellis formation, and rests with apparent conformity on the underlying Madison. There is, however, a very abrupt change in the character of the rocks at

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[a] Weed, W. H., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898–99, p. 295.

[b] Calvert, W. R., Geology of the Lewistown coal field, with special reference to coal: Bull. U. S. Geol. Survey (in preparation).

the Quadrant-Madison contact, probably indicating a hiatus. The details of distribution of this formation are shown in Pl. I.

Age.—Previous workers in this field have published statements concerning the age of the Quadrant which are somewhat at variance, having assigned the formation to both the "Lower" and "Upper" Carboniferous. While, as previously stated, no special study was made of the Quadrant formation during the investigation of the Great Falls coal field, subsequent observation has thrown some light on the age of these beds. Along the north side of the Little Belt Mountains, in the vicinity of Utica, a few miles beyond the eastern border of the Great Falls coal field, W. R. Calvert and the writer obtained a large collection of fossils from the Quadrant, and Calvert made additional collections from this formation farther east in the Judith basin.[a] These collections have all been studied by George H. Girty, who makes the following statements concerning their age:

> The several collections made in the Quadrant in this area indicate a single uniform fauna. A definite opinion as to the age of the Quadrant fauna must be reserved until more complete evidence has been obtained and more extensive investigations have been undertaken, for the facies is very largely new to the American Carboniferous. At present it seem probable that the Quadrant will prove to be of early Pennsylvanian or Pottsville age. Faunas which have an upper Mississippian facies and are younger than the Madison have been cited from the Little Belt Mountains and referred to the Quadrant. They are considerably different from the Quadrant fauna of this report, and it seems possible that three distinct faunas will be involved in the problem—a Madison fauna, a late Mississippian fauna, and a post-Mississippian fauna. The fauna of the typical Quadrant is at present unknown.

JURASSIC SYSTEM.

ELLIS FORMATION.

Character and extent.—The Ellis formation includes a basal limestone of variable thickness, ranging from 15 to 60 feet, which in places merges upward into a coarse conglomerate that passes into a medium-grained sandstone, light brown to gray in color, and more or less thin bedded. In other localities, however, the change from limestone to conglomerate is abrupt. The limestone and conglomerate contain marine Jurassic invertebrate fossils. Some of those in the conglomerate are fragmentary, but more are complete, with pebbles of limestone and quartzite several inches in diameter. The component parts of the conglomerate are bound together by a calcareous cement. The total thickness of the formation is about 80 to 120 feet. It rests unconformably upon the shale of the Quadrant formation in certain parts of the field, and upon the Madison limestone in others. (Pl. VI.)

The exposed area of the Ellis formation is not large throughout the Great Falls region. It is exhibited in the sides of the bluffs bordering Smith River and its tributary, Hound Creek, also along Sand Coulee

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[a] Op. cit.

and its various branches in the vicinity of Stockett, and along Belt Creek from Armington to the southern border of the district. East of Belt Creek the formation is exposed in the head of Otter Creek and its numerous branches from the south; also throughout a zone of varying width extending to the southeast along the northern slope of the Little Belt Mountains. Skull Butte is encircled by a narrow band of the formation. The details of distribution of the Ellis formation are shown on the geologic map (Pl. I).

The following sections illustrate the succession of the beds of the formation in different parts of the field:

Section of Ellis formation near Goodman siding, Montana.

	Feet.
Sandstone, massive, light brown to gray, weathering tan, conglomeratic and fossiliferous at base	66
Limestone, reddish brown, fossiliferous	6
Beds concealed (estimated)	18
	90

Section of Ellis formation at head of Ming Coulee, Montana.

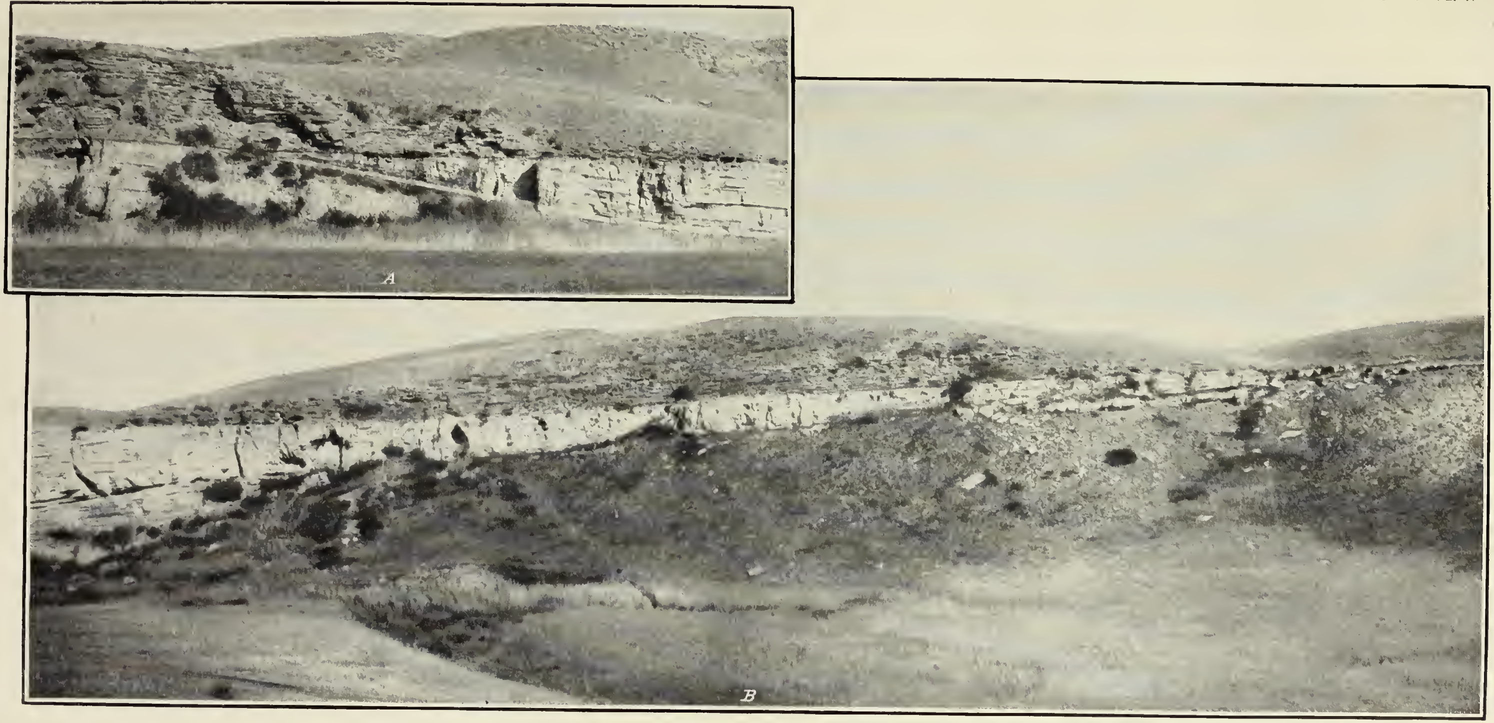
	Feet.
Sandstone, gray, weathering brown, thin bedded	60
Sandstone, gray, conglomeratic, containing marine Jurassic fossils	29
Limestone, dove colored, massive; basal member brecciated and containing Jurassic fossils	60
	149

Fossils.—Fossil invertebrates, mainly *Ostrea* and *Camptonectes*, are present in great abundance in the two lower members of the above section. The numerous specimens of these genera and a few other forms are sufficient to determine that the rocks belong to the Ellis formation, which in the Yellowstone National Park and neighboring areas yields a characteristic upper Jurassic fauna. The sandstone of the Ellis formation throughout the Great Falls region is usually not fossiliferous, but the conglomerate and underlying limestone contain an abundance of Jurassic fossils. Near the head of Hazlett Creek, in sec. 31, T. 16 N., R. 11 E., forms were collected from thin layers of limestone near the base of the Ellis formation, and were identified by T. W. Stanton as *Rhynchonella myrina* Meek?, *Ostrea strigilecula* White, *Camptonectes* sp., and *Belemnites* sp.

From the conglomerate sandstone of the Ellis formation on the east side of Otter Creek a small collection of fossils was made, from which T. W. Stanton recognized a smooth, simple form of *Ostrea*, very abundant; *Ostrea* (*Alectryonia*) sp.; and *Eumicrotis curta* Hall?.

MORRISON SHALE (?).

Character and extent.—The Morrison formation, which is extensively exposed along the Rocky Mountain front range in southern Montana



BASAL JURASSIC SANDSTONE LYING UNCONFORMABLY ON MADISON LIMESTONE NEAR STOCKETT, MONT.

A is about 1 mile south of B.

and Wyoming, is also believed to occur along the northern base of the Little Belt Mountains. In previous investigations in this field by Weed and others the Morrison formation has not been recognized, and the beds comprising it have been grouped with the Kootenai and included in the "Cascade" formation. During the last field season dinosaur bones provisionally regarded by C. W. Gilmore as of Jurassic age were found at one horizon in many different localities; and at one exposure in sec. 3, T. 16 N., R. 2 E., about 30 feet below the bone-bearing bed, a green shale containing a distinctly fresh-water fauna later than the Ellis formation was seen. These rocks, here provisionally regarded as constituting the Morrison formation, consist of sandstone and bright-colored sandy shale with scattered layers of impure limestone, many of them in lenticular form. The formation lies with apparent conformity on the Ellis and is overlain conformably by the Kootenai. The thickness ranges from 60 to 120 feet, but the exact limits of the formation are in many places difficult to determine. Fragments of bone have been found at different horizons throughout the overlying Kootenai formation, but thus far none that are sufficiently well preserved for specific determination have been discovered in this region. It is possible that future investigation may prove that the rocks here tentatively regarded as belonging to the Morrison constitute in reality a basal member of the Kootenai.

The formation is generally exposed in a narrow band on the inner rim of a low ridge formed by the harder overlying rocks of the Kootenai formation. It outcrops all along the base of the Little Belt Mountains, from the east end of the district to Smith River. Good exposures occur along the upper courses of Sage, Skull, Running Wolf, Hazlett, Surprise, Geyser, and Otter creeks and in the bluffs for some distance back from the mountains along Belt Creek, Sand Coulee, Smith River and its principal tributary, Ming Coulee. The following sections show the succession of the beds:

Section of supposed Morrison formation on the north side of Smith River in the SW. ¼ sec. 29, T. 17 N., R. 3 E., Montana.

	Feet
Kootenai formation.	
Morrison formation:	
Shale, soft, sandy	52
Limestone, light-colored, nodular	4
Shale, variegated	33
Sandstone, gray, massive	11
Shale, greenish gray, sandy	20
Ellis formation.	
	120

Section of supposed Morrison formation on the east side of Belt Creek in the NE. ¼ sec. 30, T. 18 N., R. 7 E., Montana.

	Feet.
Kootenai formation.	
Morrison formation:	
Shales, maroon and green	52
Shale, green, capped by 1½ feet of sandstone, gray	5
Sandstone, calcareous, weathering light brown	5
Shale, greenish	20
Sandstone, massive, weathering light brown	7
Shale, dark green, containing thin limestone layers	9
Ellis formation.	
	98

Section of Morrison and part of Kootenai formation in the NE. ¼ sec. 3, T. 16 N., R. 10 E., near Shannon Creek, Montana.

	Ft.	in.
Kootenai formation:		
Sandstone, gray, massive	60	
Coal (estimated)	6	
Beds concealed	60	
Morrison formation:		
Beds, concealed	22	
Shales, red and green, containing ironstone layers at base	46	
Limestone, light colored, fossiliferous	5	
Shale, green, sandy, fossiliferous	25	
Limestone, white, fine-grained, thin bedded		6
Shale, green, sandy	13	
	237	6

Fossils.—Invertebrate fossils collected from a locality where Shannon Creek was measured have been examined by T. W. Stanton, who reports three species of *Unio*, apparently all undescribed; *Neritina* sp. and *Valvata* cf. *scabrida* M. and H. Mr. Stanton's comments on this collection are as follows:

> This is a fresh-water fauna later than the Ellis and suggestive of the Morrison, although there are no identical species, with the possible exception of the *Valvata*.

From the red and green shales about 1 mile west of the above-described locality were collected saurian bones which C. W. Gilmore describes as "a portion of the centrum of a large vertebra, which, from its size, might well represent one of the large herbivorous dinosaurs of the Jurassic (Morrison)."

CRETACEOUS SYSTEM.

KOOTENAI FORMATION.

General statement.—The Kootenai formation, as determined by the present investigation, comprises the upper one-third of the Cascade and Dakota and the basal red shale included in the Colorado shale, as described by Weed[a] in the Fort Benton folio. The name Cascade,

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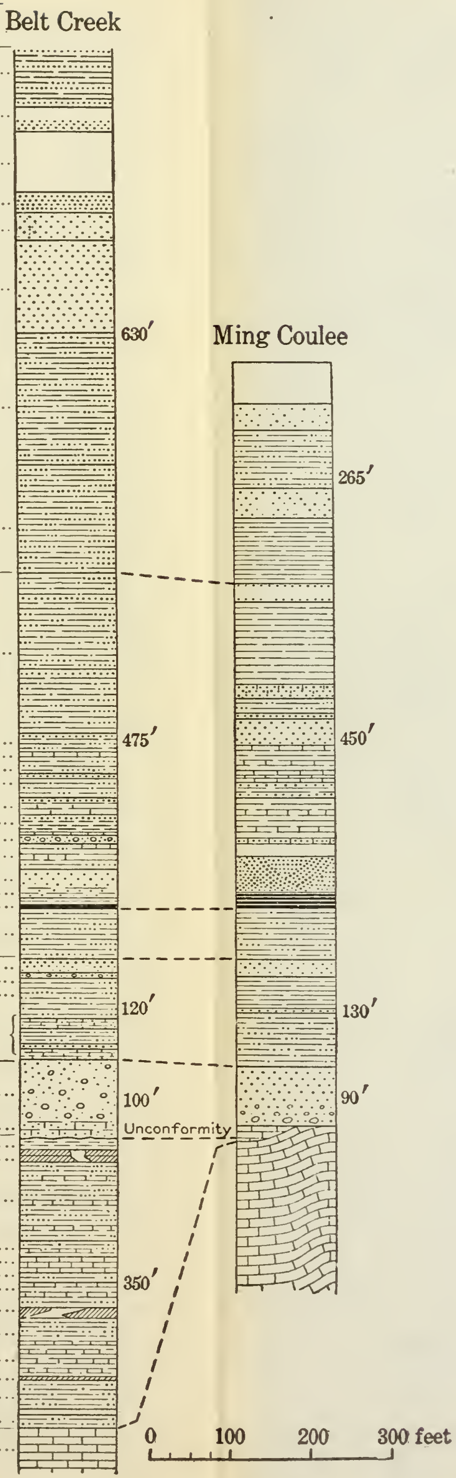
[a] Weed, W. H., Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899.

FORMATIONS.	CHARACTER OF ROCKS.
Colorado (Upper Cretaceous)	Shales, dark, with layers of sandstone
	Beds partly concealed; thin-bedded sandstone at base
	Beds concealed
	Sandstone, dark gray, soft
	Sandstone, dark gray, hard, forming bold ledge
	Sandstone, gray
	Shales, dark gray, sandy
	Shales, greenish, sandy
Kootenai (Lower Cretaceous)	Shales, red, sandy, only partly exposed
	Shales, reddish, sandy, with thin-bedded sandstone
	Limestone, light brown, compact, fossiliferous
	Shale, purplish, with lilac thin-bedded sandstone
	Shales, light, sandy, capped by sandstone
	Shales, purplish, with limestone and sandstone
	Clay, red, capped by sandstone
	Conglomerate, clay-ball, capped by rust-colored limestone
	Shales, greenish to purple, sandy, with limestone lenses
	Sandstone, gray, massive, shaly at base
	Shales, dark gray
	Coal
	Shales, greenish, soft, sandy
Morrison (Cretaceous or Jurassic)	Sandstone, gray, massive, thin bedded at base
	Conglomerate, pebbly, lenticular
	Shales, maroon and greenish, sandy
	Shales, sandy, and calcareous sandstone
	Shales, green, sandy
	Sandstone, tan-colored, massive
	Shale, dark green, containing layers of limestone
Ellis (Jurassic)	Sandstone, gray, massive, conglomeratic, fossiliferous
	Limestone, conglomeratic, fossiliferous
Quadrant (Pennsylvanian)	Shales, dark green, with beds of clay at top
	Gypsum
	Shales, variegated, sandy, alternating with limestone
	Shales, dark, with limestones at base
	Limestones, white and dove-colored
	Shale, sand, and hard, brecciated limestone
	Shale, dark green
	Gypsum, lenticular
	Shales, green, sandy, with thin white limestone at base
	Shales, green, sandy, alternating with white limestone
	Gypsum
	Shales, red and green, soft, sandy
	Shale, red, sandy
Madison (Mississippian)	Limestone, white, massive



COLUMNAR SECTIONS SHOWING STRATIGRAPHY IN DIFFERENT PARTS OF GREAT FALLS REGION, MONTANA.

as referred to a Cretaceous formation, was first used by that author in his description of the rocks of the Fort Benton quadrangle, to apply to a series of beds ranging in thickness from 225 to 500 feet. The lower part of the formation, as originally described, consisted of lavender-tinted sandstone containing at its base a workable bed of coal. During the present investigation, as previously stated, saurian bones believed by C. W. Gilmore, of the United States National Museum, to be of Jurassic age, were discovered in the lower half of the so-called "Cascade" formation, indicating that these beds are probably of Morrison age, although vertebrate remains occur in the sandstones of the overlying Kootenai. Between a horizon 45 feet below the coal bed and the top of the "Cascade" formation as above defined fossil plants of Kootenai age were collected at five different horizons, establishing beyond question the Lower Cretaceous age of this portion of the formation. On the east side of Spanish Coulee, a tributary of Smith River, at a horizon about 150 feet above the "Cascade" formation, in beds the equivalent of which in the vicinity of Belt have been provisionally regarded by Weed as of Dakota age, a large collection of Kootenai plants was procured from dark-colored shale associated with red and green shales and clay. Overlying this plant-bearing bed is about 200 feet of rocks consisting of red shale and sandstone not differing materially in stratigraphy or lithologic character from beds immediately underlying the plant horizon. The close lithologic resemblance of this upper member to the underlying well-defined Kootenai rocks, together with the apparent absence of Dakota floras in it, has been regarded by the writer as sufficient evidence for provisionally including the beds in question as of Kootenai or Lower Cretaceous age. These beds are overlain by dark-colored shale and sandstone of the Colorado formation, in the lower part of which were discovered marine saurian remains.

In this report it does not seem advisable to employ the name "Cascade" for the following reasons: First, the term has not been so extensively used in the literature as the term Kootenai; second, its usage would necessitate redefining the term, in order to separate its lowest member, which is now believed to be Morrison; third, the beds immediately overlying the "Cascade" formation can not be differentiated paleontologically from it, both being of Lower Cretaceous age, rendering it necessary to place the upper limit of the formation in question purely on lithologic grounds.

Character and extent.—The Kootenai formation consists of alternating layers of sandstone and shale, with the former predominating, especially in the lower half. The sandstones range in thickness from 10 to 60 feet, and are more or less massive in character. In the upper part shales are more abundant and are interbedded with thin layers of impure sandstone. At Belt, on the east side of Belt

Creek, where a complete section was measured, the basal member of the formation consists of a sandy shale interbedded with sandstone, the latter predominating, the whole having a thickness of about 60 feet. This member consists locally of firm, massive sandstone with only a small percentage of shale. It is overlain by coal, which here has a thickness of 6 feet, including a few thin partings. Above the coal there is a dark, coaly shale 5 to 6 feet thick, covered by 38 feet of massive light-gray sandstone. This sandstone is overlain by 138 feet of beds, consisting in ascending order mainly of alternating layers of sandstone, red shale, and clay, with an occasional limestone lens in the lower part. Above this alternating series there is about 200 feet of red shale, which constitutes the topmost member of the formation. The total thickness is about 450 feet, which may be regarded as representative of the Kootenai formation as exposed along the Belt Creek valley.

In previous reports on the geology of this region by Weed a greatly exaggerated thickness (736 feet) was assigned to beds lying between the base of the Ellis and the coal bed of the Kootenai formation. Of this amount the lower 215 feet was regarded as belonging to the Ellis and the remainder to the Kootenai formation, the presence of the Morrison between these two formations not having been recognized. During the present investigation a number of detailed sections measured along Belt Creek proved conclusively that the stratigraphic interval between the base of the Ellis and the Kootenai coal, to which Weed had assigned a thickness of 736 feet, is in reality only about 300 feet. According to the present classification the lower 120 feet of these beds has been assigned to the Ellis; an equal thickness immediately overlying, in which fresh-water invertebrates and land animals occur, to the Morrison; and the upper 60 feet, which is plant bearing, to the Kootenai. Pl. IV, which contains a number of columnar sections measured along Belt Creek valley, illustrates the character and thickness of the various formations.

On the north side of Skull Butte the base of the Kootenai consists of a soft light-gray massive sandstone, but in other respects the portion of the formation exposed in this locality agrees closely with the beds exhibited at Belt Butte. A section of the Kootenai on the north side of Skull Butte is given below:

Section of a part of Kootenai formation on north side of Skull Butte, Montana.

	Ft.	in.
Shale, reddish, sandy.		
Sandstone, gray, thin bedded	1	6
Shale, reddish, sandy, with layers of sandstone in lower part	21	
Sandstone, greenish, gray, weathering dark; thin bedded above, clay-ball conglomerate below	4	
Shale, reddish, sandy, with layers of sandstone in lower part	27	
Sandstone, gray, cross-bedded; clay-ball conglomerate in lower part	5	6

Section of a part of Kootenai formation on north side of Skull Butte, Montana—Cont'd

	Ft.	in.
Shale, reddish, sandy	30	
Sandstone, soft, thin bedded	20	
Sandstone, gray, massive; clay-ball conglomerate	3	6
Shale, red, sandy	38	
Sandstone, gray, massive; clay-ball conglomerate	5	
Shale, red, sandy	24	
Sandstone, calcareous, alternating with sandy shale	20	
Sandstone, light and dark gray, massive, fine grained	86	
Coal (estimated)	6	
Sandstone, gray, massive, soft	62	
	353	6

The Kootenai has the greatest areal distribution of all the formations outcropping within the area. It caps the surface for a great part of the district lying between Smith River and Belt Creek, and is the surface formation of the high plateaus south of Otter Creek. Beyond Otter Creek it is exposed as a band of varying width which narrows toward the east.

Fossils.—The Kootenai formation of the Great Falls district carries an abundant fossil flora of Lower Cretaceous age. Fossil plants of Kootenai age were first discovered in the Great Falls coal field in 1889 by J. S. Newberry.[a] From these fossils, which consisted of only a few species, it was possible to correlate the rocks of the Great Falls region with the Kootenai north of the international boundary line, described by George M. Dawson. In 1890, during the construction of the Great Northern Railway line between Helena and Great Falls, Mont., a larger collection of Kootenai plants was made from a railroad cut near the flood siding on the Missouri; these were reported on by Newberry in 1891.[b] About the same time that the above collection was obtained F. H. Knowlton and A. C. Peale made a small collection of plants from the same railroad cut, and the following year W. H. Weed also procured plants from this locality which were studied and described by W. M. Fontaine in 1892.[c] In 1894–95 Kootenai plants were found at a number of localities by W. H. Weed and L. F. Ward, mainly south and east of Geyser. These were described by W. M. Fontaine in Ward's second paper on the "Status of the Mesozoic floras of the United States."[d]

During the present investigation fossil plants, all of which were studied and reported on by F. H. Knowlton, were collected from five different horizons—15, 60, 70, 150, and 300 feet above the base of the Kootenai formation. The lowest horizon was on Hazlett Creek, where the following species were collected from a dark-colored sandy

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[a] School of Mines Quart., vol. 8, July, 1887, p. 329.
[b] Am. Jour. Sci., 3d ser., vol. 61, 1891, pp. 191–201, Pl. XIV.
[c] Proc. U. S. Nat. Mus., vol. 15, 1892, pp. 487–495, Pls. LXXXII–LXXXIV.
[d] Mon. U. S. Geol. Survey, vol. 48, 1905, pp. 284–315, Pls. LXXI–LXXIII.

shale 45 feet below the coal horizon and 15 to 20 feet above the base of the formation:

Cladophlebis heterophylla Fontaine.
Thyrsopteris elliptica Fontaine.
Zamites articus Göppert.
Zamites apertus Newberry (?).

Fragmentary plant remains were observed in the dark-colored clay underlying the coal at a number of localities; and a few small collections were made, the largest being from the Meredith mine, on the east side of a small coulee tributary to Geyser Creek, about 6 miles southwest of Geyser, Mont. The following were obtained:

Cladophlebis heterophylla Fontaine.
Cladophlebis constricta Fontaine.
Cladophlebis fisheri Knowlton.
Thyrsopteris elliptica Fontaine.
Acrostichopteris fimbriata Knowlton.
Dryopteris? kootaniensis Knowlton.
Adiantum montanense Knowlton.
Oleandra graminæfolia Knowlton.
Ginkgo sibirica Heer.
Podozamites lanceolatus (L. and H.) Schimper.
Zamites articus Göppert.
Nilsonia schaumburgensis (Dunker) Nathorst.

On the north side of Skull Butte, the following fossil plants were obtained from a light-colored impure sandstone about 150 feet above the base of the formation and 86 feet above the coal:

Cladophlebis heterophylla Fontaine.
Cladophlebis browniana (Dunker) Seward.
Protorhipis fisheri Knowlton.
Sequoia reichenbachi (Geinitz) Heer.
Coniferous leaves?

The highest horizon in the Kootenai formation at which plants were collected was on the east side of Spanish Coulee, a small tributary of Smith River in sec. 11, T. 17 N., R. 2 E., where the following were secured:

Thyrsopteris elliptica Fontaine.
Chiropteris spatulata Newberry.
Sequoia gracilis Heer.
Zamites apertus Newberry.

One mile south of Flood siding, about 5 miles southwest of Great Falls, on the Great Northern Railway between Great Falls and Helena, a collection of plants was made, some of which are listed below:

Dryopteris montanensis (Fontaine) Knowlton.
Sequoia gracilis Heer.
Podozamites nervosa? Newberry.
Pterophyllum montanense (Fontaine) Knowlton.

In the bluffs of Missouri River, near the Boston and Montana smelter, a large collection of Kootenai plants was made by O. C. Mortson. In this collection representatives of the following species occur:

Dryopteris montanensis (Fontaine) Knowlton.
Sequoia gracilis Heer.
Sequoia ambigua Heer.

On the south side of Missouri River, opposite the Boston and Montana smelter, a specimen of *Ginkgo sibirica* was observed by the writer, but was not collected.

The collection of fossil plants obtained from the Kootenai formation in the Great Falls region during the present investigation of the coal resources of the district is not large, but it is of unusual interest in that it contains a number of species before unknown in the Kootenai rocks of the United States, although present in the Canadian beds of this age; it contains also a species of the genus *Protorhipis* not previously found in North America, as well as some believed to be new to science.

In addition to the plants, some fresh-water invertebrates were collected from the upper part of the Kootenai during the investigation. A list is given below:

Unio farri Stanton?
Unio sp.
Corbula sp.
Campeloma harlowtonensis Stanton?
Goniobasis ortmanni Stanton?
Viviparus? sp.

These fossils are too imperfect for positive identification, but the species with which they are compared occur a few miles south of Harlowton, Mont., in beds that belong to either the Kootenai or the Morrison.

The following bibliographic list contains the more important paleobotanical papers published on the Kootenai formation:

Dawson, Sir William, On the Mesozoic floras of the Rocky Mountain region of Canada: Trans. Royal Soc. Canada, vol. 3, sec. 4, Pls. I–IV, pp. 1–22. 1885.

The name "Kootanie series" is first given and defined in this paper, p. 2.

Newberry, J. S., The Great Falls coal field, Montana: School of Mines Quart., vol. 8, pp. 327–330. 1887.

Dawson, Sir William, Cretaceous floras of the Northwest Territories of Canada: Am. Naturalist, vol. 22, pp. 953–959. 1888.

Newberry, J. S., Flora of the Great Falls coal field, Montana: Am. Jour. Sci., 3d ser., vol. 61, Pl. XIV, pp. 191–201. 1891.

Dawson, Sir William, Correlation of early Cretaceous floras in Canada and the United States: Trans. Royal Soc. Canada, vol. 10, sec. 4, figs. (in text) 1–16, pp. 79–93. 1892.

Fontaine, W. M., Description of some fossil plants from the Great Falls coal field of Montana: Proc. U. S. Nat. Mus., vol. 15, Pls. LXXXII–LXXXIV, pp. 487–495. 1892.

Ward, L. F., and Fontaine, W. M., Flora of the Kootanie formation: Mon. U. S. Geol. Survey, vol. 48, Pls. LXXI–LXXIII, pp. 277–315. 1905.

Fontaine, W. M., Notes on some Lower Cretaceous (Kootanie) plants from Montana: Mon. U. S. Geol. Survey, vol. 48, Pls. LXXI–LXXIII, pp. 284–315. 1905.

Knowlton, F. H., Description of a collection of Kootenai plants from the Great Falls coal field of Montana: Smithsonian Misc. Coll., vol. 50, pt. 1, pp. 105–128, Pls. XI–XIV. 1907.

COLORADO SHALE.

General statement.—The rocks overlying the Kootenai formation in this district consist mainly of dark-colored shale with a number of prominent sandstone members in the lower part. This shale and sandstone constitute the well-known Fort Benton formation of the Meek and Hayden upper Missouri River section, the name being derived from the town of Fort Benton, on Missouri River, about 40 miles below Great Falls. The exposures on which the original descriptions were based and by which the stratigraphic limits of the formation were determined lie far to the east in Nebraska. In northeastern Nebraska, along Missouri River, throughout the Black Hills, and along the Rocky Mountain front, the Benton formation is usually underlain by Dakota sandstone and overlain by Niobrara limestone. In the present investigation no evidence was found of the presence of Dakota sandstone as a separate formation in the Great Falls field, nor is the formation here overlain by Niobrara limestone. It is possible that in this region the Niobrara is represented by dark shale, as Stanton has suggested,[a] and there is some paleontologic evidence in support of this belief. If the upper members of the shale and sandstone series do represent deposition during Niobrara time, they can not be separated stratigraphically from the underlying Benton. For this reason the rocks which lie between the top of the Kootenai and the base of the Eagle sandstone are described as the Colorado shale. This name was used in the same sense by Weed in the Fort Benton folio.

Character and extent.—The Colorado shale is well developed in this general region, being represented by about 1,600 feet of beds. The entire formation does not occur within the area, but only the lower three-fourths, the upper members being exposed to the north in the higher portions of the Highwood Mountains. In the vicinity of Fort Benton, only a few miles to the northeast, the Colorado is essentially a shale formation with very thin beds of impure sandstone. The Mowry shale member, which constitutes a conspicuous division of the formation to the southeast along the Rocky Mountain front, is present here, but is not conspicuous, owing to the flat dips which prevail throughout the area. Along the south side of the Highwood

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[a] Geology of Yellowstone National Park: Mon. U. S. Geol. Survey, vol. 32, 1899, p. 605. Geology and paleontology of the Judith River beds: Bull. U. S. Geol. Survey, No. 257, 1905, p. 11.

Mountains and in Belt Butte the formation contains a bed of volcanic ash. The rock is pale yellowish gray, weathering white. It resembles porcelain and is overlain by rock of similar character and appearance. Samples of this rock were collected from Belt Butte and from a locality about 8 miles northeast of Stanford. Thin sections have been examined by Albert Johannsen, who describes the first as follows: "Cryptocrystalline in texture. It is very slightly anisotropic, as a devitrified glass might be. There are a few irregular anisotropic patches which are too small to be determined. There is also a little brownish decomposed material. It may be an indurated volcanic tuff or rhyolitic glass." The second is described as "a very fine grained, compact glass, consisting almost entirely of angular fragments very slightly devitrified, and a very few small, irregular grains, apparently of quartz, but too small to be determined. The rock is very homogeneous and uniform in appearance throughout the section."

The presence of a bed of volcanic ash in the Colorado shale is a local feature, for it is absent in the western part of the field.

Southwest of Great Falls, where the Colorado is well developed, its basal member consists of a soft massive sandstone, somewhat concretionary, about 30 feet thick. Above this sandstone is approximately 35 feet of rocks composed largely of dark-colored shale with a few sandstone beds. This shale is overlain by gray, coarse-grained, massive sandstone containing concretionary layers and an occasional thin bed of soft sandy shale, the whole having a thickness of about 80 feet. Above the sandstone for 300 feet the beds consist mainly of alternating layers of sandstone and shale. These are followed by 700 feet of beds composed of uniformly dark-colored sandy shale, which constitutes the uppermost member of the Colorado as exposed in this field. A good exposure of the lower half of the formation is found in Belt Butte, where the beds consist of alternating layers of massive gray sandstone and dark-colored shale with the volcanic ash member mentioned above present. A section of the beds as exposed on the west side of Belt Butte follows:

Section of Colorado shale in Belt Butte, Montana.

	Feet.
Shale, dark gray, sandy, with thin layers of sandstone	80
Sandstone, dark gray	10
Volcanic ash	30
Shale, dark colored, sandy, with thin layers of sandstone	80
Shale, sandy; or impure sandstone	20
Shale, dark, sandy	75
Sandstone, gray; forming belt around Belt Butte	50
Shale, dark, sandy in lower part	125
Shale, dark, sandy; containing massive sandstone members; locally calcareous at top	180
Kootenai formation.	
	650

The Colorado shale is exposed in a wide area extending along the south side of the Highwood Mountains from Belt Creek southeastward to the east border of the district, although much of the area, especially the eastern half, is covered by terrace gravel. Its basal sandstone members occupy the summits of Red Butte and continue westward as a plateau capping to the Missouri River valley. Smith River and its tributary Goodwin Coulee cut the basal sandstone of the Colorado, exposing the underlying Kootenai rocks. The Colorado shale occupies the surface of the highland lying between Missouri and Sun rivers, also north of these streams across the northern border of the district. Its areal distribution is about equal in extent to that of the Kootenai, as is shown by the geological map (Pl. I).

Fossils.—Invertebrate fossils were found in the Colorado shale at several localities, notably near Geyser, where collections were made at four different localities at a point 1¼ miles northwest of Geyser, *Inoceramus labiatus* Schloth. (?) and fragments of an unidentified *Inoceramus* were obtained. A mile farther northwest the following were collected:

Inoceramus—large, probably undescribed species.
Leda sp.
Nucula sp.
Cardium sp.
Prionotropis sp.

These fossils have been examined by T. W. Stanton, who regards them of Benton age. The fossils from the last-named locality are believed to represent the upper part of the Colorado shale. A few fragmentary specimens of *Inoceramus* were found on the west side of Belt Butte, on the south side of Stanford Buttes, and 7 miles northeast of Stanford, Mont. The fossils were collected in all these places at a horizon a few feet below the bed of volcanic ash above referred to. At the north end of Square Butte, which lies about 2 miles west of the area here discussed, fossils were collected at a horizon believed to be near the top of the Colorado. These were *Ostrea* sp., possibly *Gryphæa*, and fragments of *Scaphites ventricosus* M. and H. Fragmentary remains of a swimming saurian, believed by C. W. Gilmore to be a plesiosaur, were collected from a bluish shale underlying a prominent sandstone member of basal Colorado on the west side of Spanish Coulee, in sec. 10, T. 17 N., R. 2 E.

The Colorado shale rests with apparent conformity upon the underlying Kootenai, and is overlain conformably by the Eagle sandstone, the lowest member of the Montana group. Although conformable relations appear to exist between the Kootenai and Colorado formations in this region, the Dakota, which occupies a position between these two formations in other localities, is, as previously stated, believed not to be present. If this is true, there is a hiatus at this contact representing at least several hundred feet of beds. It is possible that Dakota time is here represented by marine sediments not easily separable from the Colorado shale.

TERTIARY AND QUATERNARY SYSTEMS.

TERRACE GRAVEL.

General statement.—Throughout a great part of the territory lying east of the Otter Creek divide the plateaus of different levels which occupy the interstream spaces are covered by gravel: and the intermediate slopes, especially those of gentle inclination, are in many places strewn with material which has worked down from the higher terraces. A few isolated areas of terrace deposits are found west of the divide, notably those between Williams and Otter creeks, on either side of Belt Creek below the town of Belt, and on the south side of the Missouri, below the mouth of Smith River. Smaller areas lie along the sides of the creeks and at low levels in some of the larger valleys, especially Belt Creek. These are generally too small to be shown on the geologic map. To the northwest are terraces believed to be contemporaneous in age with those of the Great Falls field, reaching far out on the plains east of the Lewis Range, but these do not extend into the area covered by this report.

Character.—The terrace gravel is diversified in character, depending on its location relative to the different portions of the adjoining mountains whence it was derived. Those deposits which occur opposite the higher portions of the Little Belt Mountains, where crystalline rocks are exposed, contain a relatively high percentage of igneous rock, but to the east, where sediments from the crest of the mountains and crystalline rocks have not been uncovered, the amount of igneous material in the gravel is small. The deposits in general consist of sand and gravel with local beds of clay. The component parts of the gravel are of varying size, ranging from that of a pea to 10 inches in diameter. In the area bordering the mountains there are some bowlders exceeding a foot in diameter. The pebbles are rounded to subangular, and none were seen which contained striations.

Mode of occurrence.—Terrace deposits of three distinct levels are found in the eastern part of the Great Falls region. The highest has been definitely recognized at only one locality—on the summit of Stanford Butte. This deposit, which has been described by Weed[a] as the Stanford conglomerate, consists of medium to large sized pebbles, not well assorted, cemented into a firm conglomerate. Remnants of this or possibly of some higher terrace gravel are found on some of the prominent points in the hilly zone bordering the Little Belt Mountains, but the correlation of the material of these localities with that of Stanford Butte is by no means certain.

The second terrace is about 100 feet below the level of the Stanford conglomerate, and carries one of the most extensive terrace deposits of the district. It occupies the high ridge east of Skull Creek, along

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[a] Weed, W. H., Geologic Atlas U. S., folio 55, U. S. Geol. Survey, 1899.

either side of Surprise Creek, in the vicinity of Stanford Butte, and extends far to the east as a prominent topographic feature on either side of Arrow Creek.

The third and lowest terrace covers the broad flat of Running Wolf Creek valley east of Stanford, and is also found at low levels on Geyser Creek and its principal tributaries. East of Stanford this terrace is only a few feet above the flood plain of the present valley. The thickness of the deposit ranges from 5 to 35 feet in different parts of the field. It lies along either side of the streams, and has smooth surfaces which slope gently away from the mountains toward the plains.

Origin of terraces.—It is apparent from a study of the composition of the gravel deposits that their source was mainly in the Little Belt Mountains to the southwest, but little definite evidence could be obtained as to the manner in which they were laid down. It is believed that the gravels were brought down by streams from the Little Belt Mountains, and spread by them over the lower plains country, as their courses were shifted from time to time, but it seems probable that the cause which resulted in the development of the different terrace levels was not normal to the streams of that period, but was accidental. Whether the terraces resulted from uplift in the region, with subsequent rejuvenation of the streams, or from changes in climatic conditions is difficult to determine. The latter seems more probable, especially in the case of the more recent terraces, which were probably formed during Pleistocene time. No definite evidence could be found to show that the older terraces were not formed by uplift.

Age.—The age of the different gravel terraces in the Great Falls field can not be definitely stated. The two higher terraces are post-Miocene to early Quaternary in age; the third and smaller subsequent terraces date from the occupation of this area by the Keewatin ice sheet, in Wisconsin time, nearly to the present day.

The conclusion regarding the age of the earlier terraces is based on the following considerations: (1) Previous workers in the Little Belt Mountains place the date of the last uplift in this general region at the close of the Miocene. After this period the region was base-leveled. Whether the oldest terrace was formed as a result of this base-leveling or at some later period is not known, but it is certain that it was not earlier than the close of Miocene time. (2) Terrace gravel believed to be contemporaneous with the oldest deposits here described occurs northwest of Great Falls, on the high divide between Sun and Teton rivers, a few miles beyond the area to which this report relates. (3) In the bottom of Sun River valley near Augusta, at least 300 feet below the highest gravel terrace to the north, terminal moraines of mountain glaciers are found. According to Calhoun,[a] in the region

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[a] Calhoun, F. H. H., The Montana lobe of the Keewatin ice sheet: Prof. Paper U. S. Geol. Survey No. 50, 1906, p. 46.

to the north material derived from local glaciers is overlain by deposits of the continental ice sheet, and from this and other observations made throughout the general region to the north he regards the local glaciers of the Lewis Range as but slightly older than those of the Keewatin ice sheet, which occupied this area during Wisconsin time. Prior to both the local and continental glaciation of this region, therefore, a period must have elapsed sufficient for the erosion of Sun River valley nearly to its present stage after the gravel capping the high divide between Sun and Teton rivers was laid down. The erosion of this valley required considerable time, so that it seems probable that the high terrace gravels north of Sun River, which are believed to be contemporaneous with the older terrace gravels in the area described, should be regarded as of early Quaternary or possibly late Tertiary age.

GLACIAL DEPOSITS.

General statement.—Glacial deposits of Wisconsin age occupy a considerable area throughout the Great Falls region. The terminal moraine of the Montana lobe of the Keewatin ice sheet enters the district at a point about 10 miles due northeast of Great Falls, extending southward across Missouri River to Sand Coulee near Gerber station. At this point it makes a sharp bend to the east and continues thus past the head of Red Coulee, thence northeastward to Belt Creek, where it crosses the northeastern margin of the district. Its location and extent, as first worked out by Calhoun[a] and later examined more in detail by the writer, are shown on the geologic map (Pl. I). In addition to the morainal deposits, extensive lake sediments were laid down in front of the terminal moraine during the occupation of this general region by the ice. Much of this material has been removed by postglacial erosion, especially on the higher lands, but all the larger valleys in front of the moraine are filled with it. Lake deposits of two different periods, an earlier and a later, have been recognized by glaciologists in this region. The limits of the earlier lake can be ascertained only by bowlders lodged on the summits of the plateaus, but a considerable part of the deposits of the more recent lake still remains as a filling in the larger valleys.

Drift.—The drift consists of crystalline erratics, small pebbles, sedimentary rocks, and a matrix of sand and clay. The greater part of the material, however, is a sandy clay of dull-green color, generally unstratified, which stands in vertical faces where trenched by streams. The character of the rocks composing the drift has been studied in detail by Calhoun,[b] who describes them as follows:

> The crystalline erratics are of such variety as to furnish specimens of the whole rock series. In a small area, not over 5 square yards in extent, the following rocks were found: Limestone, sandstone, shale, coal, granites (both fine and coarse grained and

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[a] Op. cit., Pl. V.

[b] Op. cit., p. 27.

with different percentages of quartz and feldspar), syenites, diorites, basalts, and hornblende, mica, and garnetiferous schist, and all gradations between these and gneissic rocks. The granite and the syenite rocks predominate. Basalt and rocks containing a large proportion of the ferromagnesian minerals are not so common.

In his general study of the Montana lobe of the Keewatin ice sheet Calhoun observes little variation in the nature of the bowlders throughout the length of the moraine. Limestone bowlders are more common in the northern part and sandstone bowlders in the southern part, but the character of the crystalline bowlders remains the same. The small pebbles which make up a varying proportion of the bowlders of the drift are believed by Calhoun to be of mountain origin, having been derived from a quartzite gravel formation to the northeast. Crystalline bowlders are generally common on the surface of the drift, but in the body of the material not many are found. Here even smaller pebbles sparingly occur. An explanation of the position of these bowlders in the drift is given by R. D. Salisbury.[a] The thickness of the drift within the area treated is variable, the maximum observed being between 150 and 200 feet.

Lake sediments.—The lake deposits are mainly of two kinds—large bowlders deposited on the high land by floating ice in waters of the older and more extensive lake and finely laminated sandy clay laid down by the smaller lake in the larger valleys of the Great Falls region (figs. 1 and 2). A detailed examination of the composition of these lake sediments was not made by the writer, but they were carefully studied by Calhoun, whose description is here given.[b]

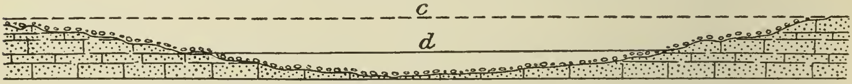

FIG. 1.—Ideal cross section showing relations between the two lake deposits in Missouri River valley west of Great Falls. *c*, Level of the more extended lake; *d*, level of the smaller lake. After Calhoun.

> The deposits of the more restricted lake consist of a finely laminated clay which when dry is hard and cleaves like shale. When wet it becomes soft and pliable, and would make an excellent molding clay. Interstratified with the clay are small crystalline pebbles one-fourth to one-half inch in thickness. They usually consist of quartz or feldspar crystals, or of small fragments containing several minerals, showing that the rock from which they were derived was granite, syenite, or basalt. Very seldom a large crystalline bowlder is found embedded in the clay.

The maximum thickness of this clay within the area treated was not ascertained, but along the Missouri near Ulm Calhoun observed[c] a thickness of 40 feet, the material containing the small crystalline pebbles characteristic of the formation farther north. Its distribution is not shown separately on the geologic map, as it is included with the alluvium. The accompanying ideal sections (figs. 1 and 2) by the

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[a] Jour. Geology, vol. 8, 1900, pp. 426-432.

[b] Op. cit., pp. 30-31.

[c] Op. cit., p. 31.

above-named author[a] illustrate the relation of the two lake deposits to the drift and ice dam.

ALLUVIUM.

General statement.—The alluvial deposits of the Great Falls region present rather unusual features. They occur intimately associated with glacial-lake sediments of the Keewatin ice sheet, and on the geologic map are not differentiated from those sediments. As previously stated, during the occupation of the region by the continental glaciers the waters of the Missouri and its larger tributaries were dammed and an extensive lake existed first in front of the ice and later in front of the terminal moraine. Sediments of this lake in its various stages filled all the larger valleys in the vicinity of Great Falls. Although much of the material constituting these sediments was brought down by streams from adjoining mountainous region, and to this extent they correspond to normal alluvial deposits along any large stream, a certain amount was contributed by the melting ice from the glacier. The alluvium, therefore, of the Missouri and its larger tributaries in this immediate district has been derived from two distinct sources. That brought in by the river may be regarded as local and that by the glacier as foreign.

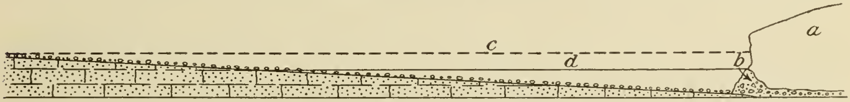

FIG. 2.—Ideal longitudinal section showing the relation of the two lake deposits shown in fig. 1 to the drift dam and the ice dam. *a*, Ice edge; *b*, moraine; *c*, level of the more extended lake; *d*, level of the smaller lake. After Calhoun.

Character and extent.—The alluvium of the Missouri, together with that of Sun and Smith rivers, its principal tributaries, ranges from half a mile to 3 miles in width. It consists mainly of fine silt and sand, with local beds of clay and gravel. Light colors prevail throughout the material. From the base of the Big Belt Mountains northeastward to Great Falls the Missouri meanders through a wide flood plain of an old valley, but east of Great Falls it flows through a narrow valley which is much younger and in which only small detached areas of alluvium are found. Alluvial deposits of small extent occur along Belt Creek and all the minor streams, but these are not shown on the geologic map.

DUNE SAND.

Character and extent.—Deposits of dune sand occupy a number of small areas in the vicinity of Great Falls. They are confined mainly to the Missouri River valley, but some are found on the lower plateaus bordering the streams. These areas, though small, present the characteristic dune-sand topography of hillocks and basins with no

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[a] Op. cit., p. 30.

developed drainage. The dunes range from 10 to 20 feet in width. They are of recent origin and in many places travel before the wind. Perhaps the largest accumulation of these deposits occurs about 1 mile southeast of Great Falls, on a plateau of the Kootenai rocks which lies approximately 100 feet above the town. Here a belt of low sand hills nearly one-half mile in width extends for 1½ miles in a northeasterly direction. Another noteworthy dune area is on the west side of the Missouri River valley about 4 miles above the mouth of Sand Coulee. Smaller areas are to be found in the larger bends of Missouri River between Great Falls and Cascade. In the valley on the west side of Smith River, near the confluence of that stream with the Missouri, there are deposits of sand which have been blown about by the wind but have not been formed into distinct dunes. At many places throughout the flood plain of the Missouri sagebrush and other small shrubs hold the sandy soil about their roots and collect additional material blown about by small wind currents to such an extent that mounds 1 to 2 feet high are built up about each bush, giving the appearance of miniature dune-sand topography. The distribution of the eolian deposits is not shown on the map.

Source.—The dune sand of the Great Falls region is derived principally from alluvial deposits of the Missouri Valley. It consists mainly of loose, fine-grained sand which in many places is not covered by vegetation, so that it is readily caught up by the wind and carried about. The sand thus transported is generally redeposited in the form of dunes in the valley or on the slopes of the adjoining highlands, but sometimes it is blown out of the valley and lodged on the bluffs above. It is believed that the deposits south of Great Falls originated in this way.

IGNEOUS ROCKS.

Igneous rocks occur in the Great Falls region mainly in the form of dikes and sheets, although stocks and unexposed laccoliths are also to be found. The dike rock of most common occurrence is a basalt, of which there are a number of varieties. It is usually very dark colored and dense, presenting on the surface a spotted appearance, due to the presence of large crystals of basaltic augite. Much of the intruded material is sufficiently hard to resist weathering better than the soft sedimentary rocks and stands out as an irregular wall or ridge. Less commonly the intrusive material is soft and crumbles easily, so that it can be traced only by lines of green vegetation growing on the surface of the decomposed rock. Rocky Ridge is formed by one of the harder basaltic dikes extending from a point near the base of Highwood Mountains southwest to Williams Creek. The intrusive rocks in this region do not, so far as known, cut or disturb to any considerable extent the areas underlain by workable coal, and consequently they are not of very great importance in the present discussion. In several places, however, intrusives appear at the surface on the margin of areas believed to be underlain by workable coal, notably on the northern border of the Otter Creek coal area, near the mouth of Williams Creek, on the upper part of Hazlett Creek, on the west side of the Sage Creek coal area, and on the northeast side of Belt Butte along the east side of the Sand Coulee coal area. In none of these localities can the intrusive rocks be traced by surface outcrops into the area underlain by workable coal, but they may possibly continue, although unexposed, sufficiently far to cut and disturb valuable coal beds. No special examination was made of the petrographic character of the intrusive rock in the eastern part of the Great Falls field, for it forms a portion of a large petrographic province of central Montana which has been studied in a detailed and comprehensive way by Weed and Pirsson. For a more extensive account of these rocks and of the larger petrographic province of which they form a part, the reader is referred to the following publications:

Weed, W. H. Two Montana coal fields: Bull. Geol. Soc. America, vol. 3, 1892, pp. 301–330.

——— Little Belt Mountains folio (No. 56), Geologic Atlas U. S., U. S. Geol. Survey, 1899.

——— Geology of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 271–461.

Weed, W. H., and Pirsson, L. V. Igneous rocks of Yogo Peak, Montana: Am. Jour. Sci., 3d ser., vol. 50, 1895, pp. 467–479.

——— ——— Highwood Mountains of Montana: Bull. Geol. Soc. America, vol. 6, 1895, pp. 389–422.

——— ——— Geology of the Castle Mountain mining district, Montana: Bull. U. S. Geol. Survey, No. 139, 1896.

——— ——— The Bearpaw Mountains, Montana: Am. Jour. Sci., 4th ser., vol. 1 1896, pp. 283–301, 351–362; vol. 2, 1896, pp. 136–148, 188–199.

——— ——— Missourite, a new leucite rock from the Highwood Mountains of Montana: Am. Jour. Sci., 4th ser., vol. 2, 1896, pp. 315–323.

——— ——— Geology of the Little Rocky Mountains: Jour. Geology, vol. 4, 1896, pp. 399–428.

——— ——— Geology and mineral resources of the Judith Mountains of Montana: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 446–616.

Pirsson, L. V. Petrography of the igneous rocks of the Little Belt Mountains, Montana: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 463–581.

——— Petrography and geology of the igneous rocks of the Highwood Mountains, Montana: Bull. U. S. Geol. Survey No. 237, 1905.

In the vicinity of Cascade, Mont., on the eastern side of Missouri River, in sec. 20, T. 17 N., R. 1 E., a large dike extends into the area from the main bed of intrusive rock constituting the north end of the Big Belt Mountains. As this dike radiates from an igneous mass at a considerable distance from those above described, samples from it were collected for the purpose of having thin sections prepared and studied. These sections have been examined by Albert Johannsen, of the Geological Survey, whose preliminary report is as follows:

> Tentative name: Andesite porphyry with latite affinities.
>
> Megascopic: A dark-gray porphyritic rock, weathering a dirty yellow. The black phenocrysts, up to one-eighth inch in diameter, become very pronounced on the weathered surface.
>
> Microscopic: Porphyritic; about one-fifth phenocrysts. The groundmass has an intersertal texture in which the irregular areas are of a dirty-brown serpentine. The phenocrysts, which are chiefly augite, are generally in broad, lath-shaped sections. A few of the feldspar crystals of the groundmass are larger than the remainder and may be classed with the phenocrysts. The groundmass consists of dirty yellowish-brown serpentine, less augite, about the same amount of magnetite, much less orthoclase, and some pseudomorphs, now serpentine, which have the form of olivine. The feldspar consists of plagioclase and orthoclase; the plagioclase varies in composition from andesine to andesine labradorite. Apparently none is more basic than Ab_{50}, An_{50}. The index of refraction is ±551.

METAMORPHIC ROCKS.

Very few metamorphic rocks are found in the plains portion of the Great Falls region, although in the mountainous districts surrounding the field the sedimentary rocks have been highly metamorphosed by intrusive dikes, sheets, and laccoliths. The Highwood Mountains bordering this field on the north have been caused by igneous intrusion in Cretaceous rocks, which were metamorphosed to such an extent that they have resisted subsequent erosion and now stand out from the surrounding plains as a cluster of high peaks. Intrusions in the form of stocks and laccoliths are more or less common along the base of the adjoining mountain ranges. From some of these intruded rock masses the overlying sediments have been removed, exposing a central core of igneous rock, around which contact-metamorphic phenomena are well exhibited. A good illustration of these conditions is found on the east side of Little Otter Creek, about 3 miles south of Mann, outside of the area here discussed.

As previously stated, intrusive rock in this district is most commonly found in the form of dikes. In most localities these have metamorphosed the sediments into which they were intruded for some distance back from the contact, converting sandstone into quartzite and shale into slate. Phenomena of this character were observed at several places, notably on the north side of the Big Belt Mountains, about 7 miles southwest of Orr, in the vicinity of Rocky Ridge, and throughout that portion of the field which lies east of Stanford. No places were observed where the intrusives had cut the workable coals and thereby altered them by metamorphism along the contact. For this reason no special study was made of the character of the contact-metamorphic rocks of the field. It is highly probable that the intrusives which cut the sediments on the northeast side of Belt Butte have had some effect on the Kootenai coals of that district, providing they extend so far east, but as there are no exposures of the coal beds the phenomena could not be observed. There are also, on the upper part of Hazlett Creek, dikes which in their northeast extension may cut and alter by metamorphism workable coals, but these dikes could not be traced on the surface into the coal area. The same is true of the dike forming Rocky Ridge, which extends southward from Highwood Mountains, but disappears at the northern edge of the Otter Creek coal area.

STRUCTURE.

PLAINS PROVINCE.

GENERAL CONDITIONS.

Throughout the plains portion of the region described the structure is relatively simple. The rocks as a rule lie nearly horizontal, dipping with a small angle to the north and east, away from the mountains, but in the mountainous portion the structure is more complex. Although low dips of 3° to 5° prevail throughout the plains province, and the district is one of little disturbance, the rocks on closer examination are found to be gently folded into a series of shallow synclines and low anticlines. This structural feature is scarcely perceptible to the casual observer, being revealed only by a careful examination of the beds exposed along the sides of the larger streams, such as Otter and Belt creeks and Smith River and its principal tributaries. The major axes of these folds appear to be roughly parallel to the Little Belt Mountains uplift, but the folds are only of slight magnitude and the individual warps are broad. The largest and most perceptible of the synclinal depressions crosses Otter Creek between the mouth of Williams Creek and the Nollar mine. Its effect is to carry the coal-bearing rocks of the Otter Creek area about 100 feet below Otter Creek valley for a distance of 3 or 4 miles.

The slight deformation of the coal-bearing rocks has had an important bearing on the development of the coal beds of this field. Wherever stream valleys cross the coal-bearing areas and cut sufficiently deep to expose the coal, they produce favorable conditions for mining. Owing to the horizontal position of the beds, entries can be driven for long distances nearly at right angles to the direction of the dip, which is in general to the north, without producing an appreciable lift in the haulage of the coal. The gentle northward dip of the coal-bearing rocks can be turned to advantage in mining by driving the main entry at an angle greater than 90° with the direction of the dip, thus causing the entry to extend up the dip sufficiently to produce natural drainage of the workings. Though in general the rocks lie nearly horizontal throughout the Great Falls field, there are minor undulations in the strata which are too local to be observed on the surface, but which are shown in the maps of the mine workings. Some of these cause more or less difficulty in mine haulage, making it necessary to use special appliances to fit the topographic conditions in the mine.

DOMES.

Local doming of the strata, due to laccolithic intrusion of igneous rock, is more or less common along the north side of the Little Belt Mountains and in the vicinity of the Judith Mountains, farther east. Skull Butte, in the plains province at the east end of the district, is without doubt a domal uplift of this character. It is nearly circular in outline, its greatest diameter being about 1½ miles, and its quaquaversal dips ranging from 20° to 30°. Erosion of its center has not advanced sufficiently to uncover igneous rocks. This uplift exposes the coal in the steeply dipping beds about its base.

In the vicinity of Stockett local uplift and erosion occurred prior to the deposition of Jurassic sediments, as is shown by the unconformable relations of Jurassic sandstone and Madison limestone. Exposures of the limestone occur in which the strata are tilted and eroded, with Jurassic sandstone deposited across the upturned ends. The strongest dip of the limestone beds seen was about 10°. The various formations in this vicinity are perceptibly thinner than elsewhere, a stratigraphic feature probably due to the presence of the dome during the deposition of these sediments. The unconformable relations of the Carboniferous and Jurassic formations, and the moderately steep dips of the latter as exhibited in Sand Coulee, about 2 miles east of Stockett, are shown in Pl. VI. This doming of the Carboniferous rocks in the Stockett region is probably not of wide extent, but its exact limits can not be ascertained owing to the lack of exposures. Its north-south dimension, as shown by outcrops along Sand Coulee, is about 4½ miles, but its east and west boundaries are not known. At Stockett and along Sand Coulee valley, owing to the thinning of the Jurassic and Lower Cretaceous formations, also to the absence of the Quadrant in the vicinity of the dome, the coal horizon occurs only about 150 feet above the Madison limestone, which is exposed in the bottom of the valley. This feature might be misleading to prospectors who are not familiar with the local conditions about Stockett, for in other parts of the Great Falls coal field, especially along Belt Creek and in the Otter and Sage Creek areas, the coal bed is separated from the Madison limestone by about 650 feet of rock.

At the head of Ming Coulee, where coal of workable thickness is exposed, the beds dip steeply to the northwest. These local dips are due to a large dome farther south, outside of the area treated in this report. The Quadrant formation is also absent, causing the coal bed to occur about 250 feet above the top of the Madison.

On Boston Coulee, about 2½ miles west of Eden, a local dome of the strata exposes the coal-bearing bed along Boston Coulee for about 1½ miles, and also to the southward up a small tributary of that coulee for an equal distance. This small uplift, which causes the coal outcrop to take a T-shaped form, is shown on the coal map (Pl. II).

FAULTS.

No large faults occur within the area here discussed, but minor faults are not uncommon, especially in the vicinity of Belt and Stockett. The throw of these faults ranges from 5 to 20 feet, and their presence is usually difficult to detect on the surface. They are generally first encountered by miners who are working the coal bed, and in some places their presence has caused considerable difficulty in mining operations. At Belt, on the west side of Belt Creek, such a fault extends nearly west for about 1½ miles, displacing the coal bed a few feet and causing difficulty in operations along the north side of the underground workings of the Anaconda Copper Mining Company's mine. In Armington Coulee, about half a mile above the mouth, a sharp fold in the beds trends northward toward Belt Butte. The beds may possibly be more or less fractured along its axis, but exposures at this place were inadequate for positive determination of this point. Other small displacements have been reported from some of the smaller mines along the east side of Belt Creek in the vicinity of Armington and Belt, notably in the Richardson mine and to a less degree in the Smauch and Millard mines, but these faults appear not to cause any appreciable displacement of the sediments at the surface. On the north side of Stockett a small fault in the Madison limestone has a throw of about 15 feet, extending east and west. The Cottonwood Coal Company reports that a small north-south fault in the coal-bearing rocks was encountered in mining about three-fourths of a mile east of the town; but no evidence of this fault was observed on the surface. The minor faults throughout the Great Falls coal field are not shown on the geologic map. It is possible that many such small faults are scattered over the field and will be discovered on more extensive development of the coal deposits, but it is difficult if not impossible to locate them, owing to the fact that their throw is generally insufficient to be perceptible on the surface.

LITTLE BELT MOUNTAINS.

The general structure of the Little Belt Mountains, which border this area on the south, is that of an anticlinal uplift with sharply dipping sides and a flat summit. In the central portion of the range the stratified rocks lie nearly horizontal, but along the northern flank of the uplift, as found on the head of Geyser Creek, the limestone dips at an angle of 15° to 20° toward the lower plains country. As previously stated, the simple structure of the northern part of the uplift has been considerably modified by the intrusion of igneous rocks in the form of laccoliths, which have caused local doming of the strata in many places. Only one of these laccolithic domes lies within the area described, but there are others, such as those east of Kibby and in the head of Dry Wolf Creek, whose marginal structure extends into the district. In the vicinity of the larger intruded masses of igneous rock the dips are in many places steep and variable, but in that portion of the mountain front where local intrusions have not disturbed the strata, they dip away normally from the uplift at angles of 6° to 12°, lessening gradually toward the lower plains country.

HIGHWOOD MOUNTAINS.

The Highwood Mountains, which border on the north the east end of the area described in this report, are structurally of a different type from the Little Belt Range. They consist of a group of isolated peaks, which were formed by igneous intrusions in Cretaceous rocks that were horizontally bedded or slightly inclined toward the east. Subsequent to this intrusion stream erosion carved out this cluster of peaks from the surrounding plains.

ECONOMIC GEOLOGY.

GENERAL STATEMENT.

The mineral resources of the area treated in this report are somewhat varied, but the principal one at present is coal. Fire clay of a superior quality is found in beds of workable thickness along Belt Creek and its tributaries, and at many places throughout the district raw materials suitable for the manufacture of Portland cement can be obtained. Gypsum deposits occur at different horizons in the Quadrant formation near Riceville, and at Goodman this mineral has been mined in a small way for a number of years. Building stones of different varieties, also limestone, are common in many parts of the field. Sand and gravel can usually be obtained locally. Iron pyrite is mined as a by-product with the coal and shipped to Great Falls, where it is used in the process of pyritic smelting.

COAL.

GEOLOGIC OCCURRENCE.

Throughout the Great Falls coal field the coal occurs in the lower part of the Kootenai, or Lower Cretaceous rocks, mainly at a horizon about 60 feet above the base of the formation. Coal of workable thickness is not continuous, however, at this horizon, but varies locally.

This irregularity of occurrence is a characteristic feature of the beds of this field which was early observed in the investigation, and an effort was made to ascertain as far as possible, from a study of the outcrop, the limits of the areas underlain by workable coal. These coal areas, or basins, as they have previously been designated by Weed,[a] are three in number and include a total area of approximately 334 square miles. The largest, comprising about 231 square miles, lies south of Great Falls, extending from a point a short distance east of Belt Creek beyond Smith River. (See Pl. II.) It is possible that the coals of this basin continue to the south throughout the territory lying between the Little and Big Belt mountains, but no examination was made of this region. The district examined is drained by Sand Coulee and its tributaries, and is known as the Sand Coulee area. To the east the next district underlain by coal of commercial importance lies between Little Otter and Geyser creeks, and is designated the Otter Creek area; it is the smallest coal area in the field, including only about 37 square miles. Still farther east, in the vicinity of Skull Butte, there is a third coal area, which, owing to its nearness to Sage Creek, the main drainage channel of the district, is called the Sage Creek area. It includes about 66 square miles.

SAND COULEE AREA.

LOCATION AND EXTENT.

The Sand Coulee coal area, which lies south of Great Falls, is 6 miles wide and from 30 to 40 miles long. The exact limits of the area underlain by workable coal are difficult to determine, for it is only along the valleys of streams that cross the area, such as Belt Creek, Sand Coulee, and Smith River and their tributaries, that the coal bed can be studied with respect to its disposition to thicken or thin in any given direction. In the plateau district between these valleys the coal is concealed by 200 to 300 feet of overlying Kootenai rocks, which the smaller streams traversing the plateaus have not cut down sufficiently to expose the coals. As the rocks dip gently away from the mountains, the outcrop of the coal bed extending across the plateau from one stream valley to another occurs far up the slope in the foothill zone, where the coal is usually represented by a thin bed of carbonaceous shale. Under these conditions it is apparent that the width of the coal basin can only be inferred from the thickness of the beds along the stream valleys. As these valleys are more or less widely separated, the lateral extent of the coal area in the plateau region is largely conjectural.

Along Belt Creek, which crosses the east end of the area, the coal bed thins rapidly to the south and becomes shaly at a point near the

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[a] Weed, W. H., Bull. Geol. Soc. America, vol. 3, 1892, pp. 301-330.

mouth of Otter Creek. Toward the north the same is true, although in a less marked degree, to a point a short distance above the mouth of Little Belt Creek, where the dip of the rock carries the coal beneath the river. The bed is thickest in the vicinity of Armington and Belt, and in either direction from this zone there is a perceptible thinning. The eastern border of the workable coal area can not be definitely determined, for the coal east of Belt is not exposed, but along the lower part of Otter Creek the workable bed thins rapidly to the east, a condition which is believed to indicate that the eastern limit of the workable coal should be placed not more than 2 miles east of Belt Creek.

According to exposures along Sand Coulee, the coal bed thins to the south, near the northern line of T. 18 N.; and to the north in sec. 2, T. 19 N., R. 4 E., it is only a few inches thick. The bed reaches its maximum thickness between Straight and Giffen coulees, where the larger coal mines are located. In the Smith River valley, near the mouth of Hound Creek, the coal bed has a good workable thickness, which it maintains toward the north, possibly with slight thinning as far as sec. 1, T. 17 N., R. 2 E., where the bed passes beneath the river. How far workable coal extends northwest of this point is not known, but it seems probable that it continues for at least 2 or 3 miles. The southern limit of the Sand Coulee area was not ascertained, for the investigation did not extend beyond the southern border of T. 17 N., where a local fold of the strata carries the coal beneath the river; as it is of workable thickness at the southernmost point examined, it may possibly continue thus for some distance.

On upper Ming Coulee the coal bed has a maximum thickness of 8 feet, but 2 miles farther up this stream the dips are steep and the bed occupies the summits of high hills, where the covering is thin and the coal more or less shaly. Along the north side of the wagon road leading from Ming Coulee to Rocky Coulee the coal bed has been prospected at many places, especially in secs. 21, 22, and 14, T. 17 N., R. 3 E. In most of these prospects the coal horizon was marked by only a few inches of carbonaceous shale, which locally thickens and in one place becomes nearly workable. From these observations it is believed that the southern limit of the Sand Coulee area in this part of the field lies some distance north of the wagon road. The limits of this area as based on the evidence are shown on Pl. II.

CHARACTER AND THICKNESS OF COAL BED.

The Sand Coulee area is underlain by one coal bed of commercial importance. In this bed, consisting of coal interbedded with layers of bone, shale, and clay, the coal content ranges in thickness from 6 to 14 feet in different parts of the field. At Belt, in the northeast end of the area, where the bed has been opened at many places, the average thickness of twenty-six measured sections is 4 feet 7 inches. At Sand Coulee fourteen measured sections give an average thickness of 8 feet 7 inches, and along Smith River, where fewer openings have been made, an average of five sections shows a total thickness of 7 feet 6 inches of coal. In the vicinity of Belt the coal is divided into three distinct benches—a lower, middle, and upper. The lower and upper benches are in many places about equal in thickness, the middle bench being considerably thinner. (See Pl. VIII.)

At Sand Coulee the coal bed generally occurs in two principal benches, the upper being much thicker than the lower. (See Pl. X.) Above the uppermost bench worked, however, there are in some places, notably in the Smith River district, two higher layers of coal which have a maximum measured thickness of 5 feet 8 inches. From a comparison of the average thickness, number, and order of the various coal benches in the Belt, Sand Coulee, and Smith River mining districts, it is apparent that the coals of this basin are of broadly lenticular character and it seems probable that the total thickness of coal contained in the coal-bearing zone is greatest in the Sand Coulee mining district.

Graphic sections of the coal in the Sand Coulee, Otter, and Sage Creek areas are shown in Pls. X–XII. In the following discussion of the coals of these areas individual sections are referred to by numbers corresponding to those used on these plates.

DEVELOPMENT.

Development of the coal resources of the Great Falls coal field was first begun in the Sand Coulee basin at Belt, where, in 1876, a small mine was opened, the coal being shipped overland to Fort Benton, a town situated near the head of navigation on Missouri River. For the first few years the coal output of this field was small, but with the opening of mines at Sand Coulee, on Smith River, which took place a few years later, the amount was increased. In 1885 the combined production of the Belt and Sand Coulee mines was 1,900 tons, of which 1,200 were from the Belt mines. During the following year the output of these two localities amounted to only 1,400 tons, the greater part being supplied by the Sand Coulee mines. The reports on Cascade County for 1887 give a relatively small yield, but during the following year, with the completion of railroad facilities to Sand Coulee, the total coal production of the region was materially increased. From 1888 to 1892 the annual coal output of the Sand Coulee basin grew steadily with the improvements made in the facilities for handling coal at the Sand Coulee mines; during 1893 the total production of the region increased over 100 per cent. Since 1880, when the first systematic record of the coal production of Montana was kept, Cascade County has been one of the largest producing counties in the State. Its relative output, with respect to that of the State as a whole, is shown in the following table:

Coal production of Montana and Cascade County from 1880 to 1906, inclusive.[a]

[Short tons.]

Year.	Montana.	Cascade County.	Year.	Montana.	Cascade County.
1880	224	....	1895	1,504,193	713,877
1881	5,000	....	1896	1,543,445	1,101,298
1882	10,000	....	1897	1,647,882	1,138,590
1883	19,795	....	1898	1,479,803	988,821
1884	80,376	....	1899	1,496,451	965,378
1885	86,440	1,900	1900	1,661,775	1,123,395
1886	49,846	1,400	1901	1,396,081	789,407
1887	10,202	....	1902	1,560,823	761,572
1888	41,467	4,600	1903	1,488,810	733,064
1889	363,301	166,480	1904	1,358,919	599,158
1890	517,477	200,435	1905	1,643,832	826,026
1891	541,861	198,107	1906	1,838,635	991,417
1892	564,648	242,120			
1893	892,309	516,460	Total	22,730,990	12,702,465
1894	927,395	638,960			

[a] Mineral Resources U. S., 1880 to 1906, inclusive, U. S. Geol. Survey.

Although at the present time coal prospects and small mines are located at many different places throughout the Sand Coulee area, development is confined chiefly to three localities where stream valleys crossing the district cut and expose the coal-bearing rocks. These districts of principal development are along Belt Creek, Sand Coulee, and Smith River.

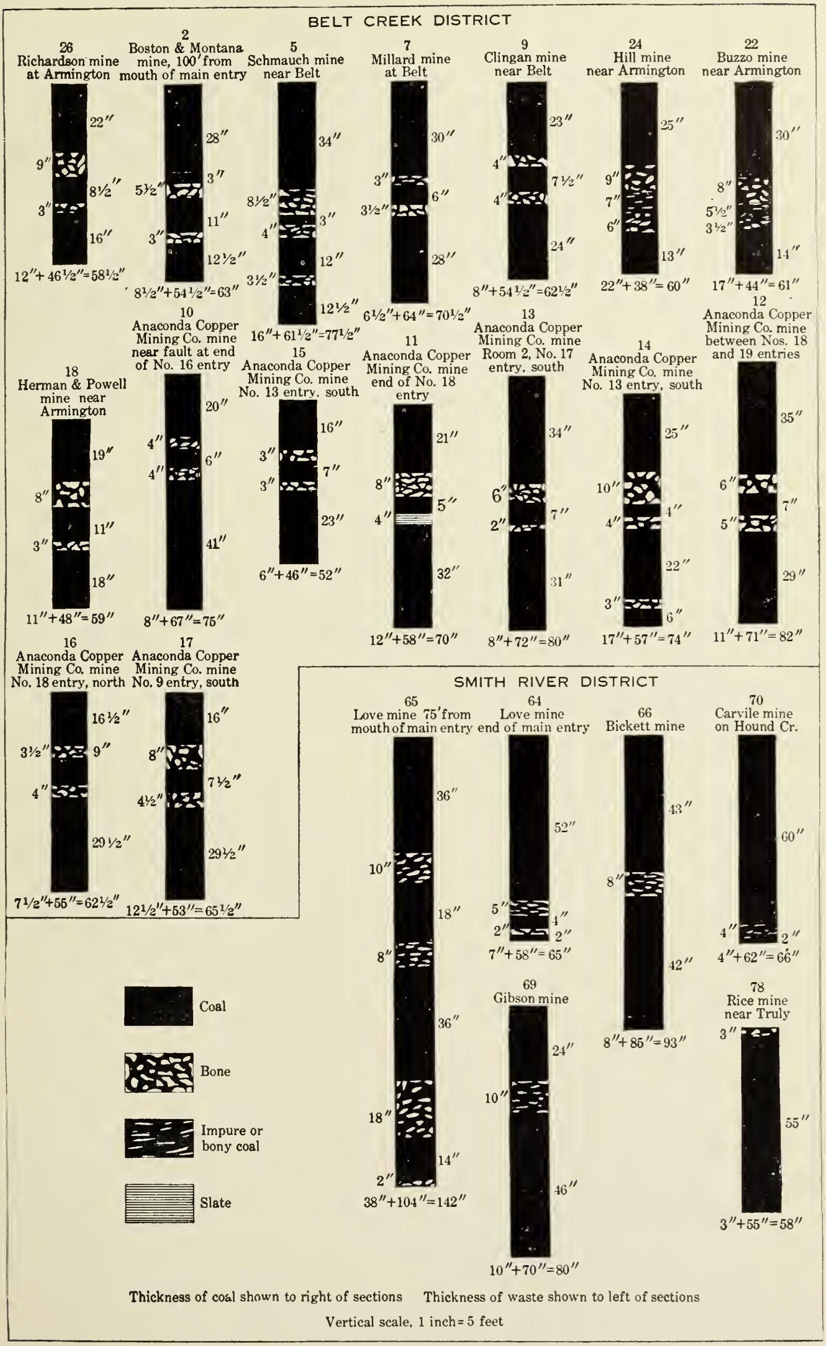
BELT CREEK MINES.

GENERAL STATEMENT.

Along Belt Creek and its tributaries near the town of Belt the coal bed has been extensively prospected and a number of mines are now being operated. The mine of the Anaconda Copper Mining Company is the largest in the district, but there are four smaller ones which are worked continuously, and seven abandoned mines, some of which have produced considerable coal in the past. Prospecting has been extensive, especially along Neel Creek, on either side of Belt Creek, and in Armington Coulee. A number of diamond-drill prospect holes have been bored by the larger companies on the plateau west of Belt Creek in order to determine the character of the coal bed underlying their holdings. The location of the mines are shown on Pl. II; sections of the coal beds are shown on Pl. VIII.

MINES OPERATED.

Anaconda Copper Mining Company mine.—The mine owned and operated by the Anaconda Copper Mining Company, of Anaconda, Mont., is located on the west side of Belt Creek, at the town of Belt. (See Pl. IX.) The principal coal holdings of the company, which



SECTIONS OF COAL IN BELT CREEK AND SMITH RIVER DISTRICTS, MONT.

comprise several acres, lie in secs. 26 and 27, T. 19 N., R. 6 E. This mine was first opened in 1895, and has been in continuous operation since that time. At present the company employs a large force of men and produces a considerable tonnage. The mine, however, is not worked at its full capacity, the output being controlled by the requirements of the company's plant at Anaconda, a point to which much of the coal is shipped.

The bed at this place has an average thickness of 6 feet, including partings, and occurs in three benches. The lowest bench is about 2 feet 6 inches thick, and is overlain by 2 to 4 inches of bone, followed by the middle bench, which is usually about 7 inches thick. Above this 7-inch layer occurs bone parting 3 to 8 inches thick, followed by a bed of coal 1 to 3 feet thick, constituting the uppermost bench. There appears to be little difference in the physical properties of the coal in the different benches. The bed usually has a shale roof and floor and lies nearly horizontal, dipping only slightly to the north. Sulphur in the form of pyrite nodules occurs in all the benches. A number of graphic sections of the coal bed in this mine are shown in Pl. VIII.

The underground workings of the mine are very extensive. The main entry has been driven for about 1½ miles from the outcrop, with numerous side entries to the north and south one-half mile or more in length. The entire workings cover an area of about 600 acres. The coal is taken out by the room-and-pillar system and brought to the surface by cable haulage. The mine is provided with a double entry, and ventilation is effected by a large fan located near the entrance. Electric lighting is used only in the main entries, and the water is removed by large pumps.

Owing to the large amount of impurities present in the bed it is necessary to wash the machine-mined coal. The method employed is as follows: The coal is carried from the mine in pit cars having a capacity ranging from 2 to 2½ tons each, by means of a cable and tail rope. A trip consists of 48 cars, which on arriving at the mouth of the mine are uncoupled and allowed to run one by one down a gravity incline from which the car is switched onto one of three tipples, according to the character of the coal it contains. After the cars are unloaded they are gathered again on a single track and returned to the mine.

The tipple over which the hand-mined coal is dumped is connected directly by chute to the railroad cars below. The two remaining tipples are connected with a heavy sharp-toothed crusher by long chutes, which are sufficiently large to serve as temporary storage bins. At the crusher all the machine-mined coal is reduced to a small size. It is then carried by means of an inclined conveyor to the top of the washery, which consists of three large washers and a number of jigs. The amount of coal cleaned at this plant ranges from 250 to 300 tons a day.

The large washer consists of a steel chamber in the form of an inverted cone, inside of which are projecting arms and stirring plates revolved by a driving gear above. The water supply enters at the bottom from a perforated pipe. The coal is introduced at the top from a chute and is kept in a continual state of agitation by a current of water. As it is lighter than the impurities, it remains at the top and passes out through the overflow into conveyors, while the water and sludge drain through the hopper into a sludge tank. The impurities sink into a lower chamber of the washer, which is provided with two valves, one above and one below. When this chamber is filled, the upper valve is closed and the lower opened to discharge the refuse. By this process the coal is cleaned rapidly, but the results on the whole are not so satisfactory as those obtained by the jigs.

The jig washer consists essentially of a large wooden tank divided into two compartments, one containing a screen on which are placed a number of small pieces of feldspar, the other provided with a piston moved up and down by means of an eccentric, imparting to the water the necessary pulsations. By this means the water is forced up through the screen, lifting the unassorted material and allowing it to settle again, thus affording an opportunity for the products of different specific gravity to adjust themselves according to the law of equally falling particles. The coal remains at the top of the wooden tank, the slate next below, and the pyrite at the bottom. These products of separation are drawn off through gates placed at proper heights in the sides of the jig and are carried away by screw conveyors—the coal to a large bin, where it is allowed to drain; the pyrite to an elevator, where it is rinsed and dropped into railroad cars; and the slate to the waste pile. The water used in the washery is taken to a tank outside the plant, and after the sediments which it contains have settled to the bottom, the clear water is drawn off from the top and pumped back into the washer.

The iron-pyrite nodules removed by the above-described process are shipped as a by-product to the large smelters at Great Falls, where they are used as an additional fuel and flux in the blast-furnace charge. By this utilization the pyrite pays for its separation from the coal.

Coal from the middle bench of the Belt Creek bed was formerly coked, and 100 ovens having a capacity of 3 tons each were built for this purpose. It was found, however, that the bench of coking coal was too thin to pay for its separation from the other varieties of coal, and consequently the coke ovens are not now used. A view of the Anaconda Copper Mining Company's plant at Belt is shown in Pl. IX.

ANACONDA COPPER MINING COMPANY'S COAL PLANT AT BELT, MONT.

Schmauch mine.—The Schmauch mine, situated on the east side of Belt Creek at Belt, nearly opposite the Anaconda Copper Mining Company's mine, is probably the largest of the smaller openings. This mine is worked continuously by a few men, but it has only a small output, which is sold to ranchmen in the vicinity of Belt. The entry extends several hundred feet from the outcrop, but the exact length could not be measured owing to cavings in the mine. The bed lies nearly horizontal, dipping slightly to the north. A representative section shows a thickness of about 6½ feet, consisting of three benches. The lowest is 28 inches thick, containing a bone parting 3½ inches thick 12½ inches above the base. Above this bench is a 4-inch layer of bone, followed by 3 inches of coal, constituting the middle bench. This is overlain by 8½ inches of bone, which is followed in ascending order by a bed of coal 34 inches thick—the top bench (5). The occurrence of a bony layer in the lower bench of coal is unusual in this district.

Millard mine.—The Millard mine is situated a few hundred yards south of the Schmauch mine, on the same side of Belt Creek. Here an entry has been driven about 700 feet from the outcrop, with side entries leading to the north and south. The bed is about 6 feet thick, containing partings which separate the coal into three benches, the lower 28 inches, the middle 6 inches, and the top 30 inches (7). The lowest bench is regarded by the miners as containing the best quality of coal, that of the middle and uppermost benches being of a slightly inferior grade. The Millard mine has a very small output, and most of the coal is sold in the town of Belt.

Richardson mine.—On the east side of Belt Creek at Armington is another mine, owned by Matthew Richardson, which is worked during the winter months. The coal here exhibits the usual thickness of about 4½ feet, including partings. The three characteristic benches are represented—a lower, middle, and upper. The uppermost has a thickness of 1 foot 10 inches, the middle and lowest are 8½ and 16 inches thick, respectively. A section of this bed is shown in Pl. VIII, No. 26. The coal is bright and clean looking, and in composition does not differ materially from the average coal found near Belt. The output of the mine, which is small, is sold in Armington and to ranchmen along Belt Creek valley.

Orr mine.—About 1½ miles north of Belt, on the east side of Belt Creek, there is a mining property owned by the Orr Brothers, which is worked to a certain extent, chiefly in the way of development. A main entry has been driven 700 feet from the outcrop, with side entries of considerable length.

The coal appears to be of inferior quality and the large amount of material taken out in excavating the entries could not be placed on the market. The coal is dull or lusterless and is not firmly bedded.

An analysis of an air-dried sample shows about 44 per cent fixed carbon, 21 per cent volatile matter, 28 per cent ash, and a small amount of sulphur. A representative section of the mine shows five benches of coal, with an aggregate thickness of 4 feet 5 inches. The lowest bench is 10 inches thick, followed by 3 inches of bone, which in turn is overlain by 10 inches of coal. Above this coal is a 12-inch layer of bone overlain by 7 inches of coal of a rather inferior variety. Over this coal is 10 inches of bone followed by 22 inches of coal, constituting the uppermost bench of the bed. A comparison of this coal bed with those in the Schmauch and Millard mines indicates that partings have developed in both the lower and upper coal benches.

ABANDONED MINES.

The remaining small mines of the Belt district are the Hill, Buzzo or Hill, Boston and Montana, Herman & Powell, Watson, Brady, and American Smelting and Refining Company.

Hill mine.—An abandoned mine, said to be now owned by J. J. Hill, is located on the west side of Belt Creek at Armington. A large entry has been excavated, and, to judge from the size of the dump, considerable coal was taken out. A section of the bed shows 3 feet 2 inches of coal, not including three layers of bony coal which occur near the middle (24). The coal is apparently of good quality, but contains the usual amount of sulphur in the form of iron-pyrite nodules. The uppermost bench is characterized by joint planes running in opposite directions, separating the coal into small cubical blocks.

Buzzo or Hill mine.—About one-fourth mile south of the abandoned Hill mine, on the same side of Belt Creek, there is another opening known as the Buzzo mine, also owned by J. J. Hill. This mine is more or less caved at the mouth of the entry, but the general succession of the members in the coal bed was obtained. Three benches of coal are present, the lowest 14 inches, the middle, which is very impure, 5½ inches, and the uppermost 30 inches thick (22). The coal appears to be of good quality in the uppermost bench, but that found in the middle bench is inferior. No analysis was made. The entry is said to be 500 feet long, but as the mine was flooded it was impossible to examine in detail the underground workings. The mine has a sandstone roof and a clay floor.

Boston and Montana mine.—The Boston and Montana mine, located about 500 yards south of Orr Brothers' mine, in the SE. ¼ sec. 23, T. 19 N., R. 6 E., contains a bed of coal similar in many respects to that found in the Orr mine. It has a sandstone roof and shale floor. A graphic section of the bed is given in Pl. VIII, No. 2. The three benches have an aggregate thickness of 54½ inches. The lowest contains a layer of bone, or bony coal, 12½ inches above the base. This bench is overlain by 5½ inches of bone, which is followed by the middle bench of coal, 3 inches thick. Above the middle bench there is a thin bony parting underlying 28 inches of impure coal, the top bench of the bed. A comparison of the sections at the Orr and at the Boston and Montana mine appears to indicate that the quality of the coal becomes better to the south.

Herman & Powell mine.—About 300 yards north of the Richardson mine, on the eastern side of Belt Creek at Armington, there is an abandoned opening known as the Herman & Powell mine. Two entries 75 feet apart have been excavated on the bed. The south entry is 250 feet long, extending in a southeasterly direction, but has no side entries. A section of the coal bed in this entry shows 4 feet of coal separated into three benches, the lowest 18 inches, the middle 11 inches, and the uppermost 19 inches thick (18). The mine has a slate roof and a clay floor. The north entry is 350 feet long and runs in a northeast direction. It has one entry on the southeast, which branches from the main tunnel 75 feet from its mouth. A section of the bed in this entry shows a thickness of 54½ inches divided into lower, middle, and upper benches, measuring 16½, 11, and 27 inches, respectively. The roof is dark-colored shale and the floor clay. This mine has not been operated for several years, but according to reports considerable coal was formerly taken out.

Watson mine.—About one-fourth mile south of the Richardson mine a tributary canyon known as Armington Coulee enters Belt Creek valley. On both sides of this coulee the coal bed is exposed, and several openings have been made. The largest on the south side of the coulee is known as the Watson mine. Here an entry has been excavated for a distance of 160 feet, exposing a bed of coal, including partings, 5 feet 1½ inches thick. Of this amount 4 feet 1 inch consists of coal, the remainder of dark-colored bony material. Three benches are recognized, the lowest 13 inches thick, the middle 13½ inches, and the uppermost 22½ inches. The middle bench appears to be of an inferior quality, although no analysis has been made. The lower bench contains a large amount of sulphur in the usual form. The bed has a slate roof and shale floor.

Brady mine.—On the north side of Armington Coulee, directly opposite the Watson mine, there is an abandoned opening known as the Brady mine. The entry at this place extends 150 feet from the outcrop, with one room on either side. The coal bed has a total thickness of 55½ inches. The coal of the lower bench is bright looking, but contains much sulphur in nodular form. The coal in the upper part of the top bench has a dull appearance and is probably of inferior grade.

American Smelting and Refining Company mine.—On the west side of the main road between Armington and Belt, near the Belt cemetery, there is an abandoned entry which was excavated by the American Smelting and Refining Company. This entry is well timbered, and the indications are that plans were laid for extensive development. The property is now abandoned, and the entry is caved so that it could not be examined for more than a few feet from the mouth. No information was obtained regarding the quality of the coal.

PROSPECTS.

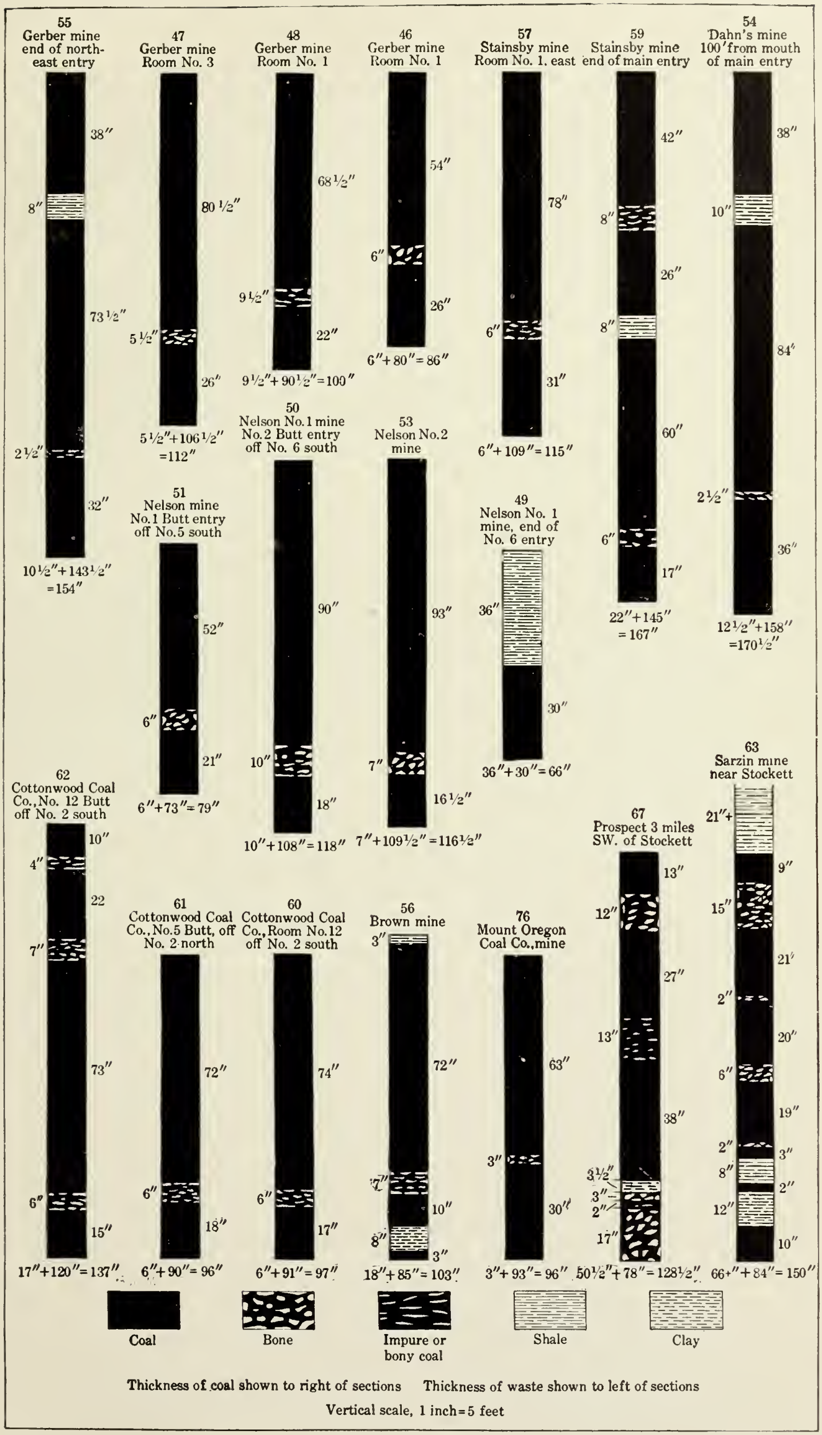
Entry prospects.—Considerable prospecting has been carried on in Belt and vicinity. Along Neel Creek, one of the principal tributaries of Belt Creek from the west, coal prospects can be seen at short intervals on either side of the canyon. Few of these prospects extend more than a few feet from the outcrop and they appear to have been opened more to determine the thickness of the coal bed than with the intention of developing a mine. One of the largest of these prospects, which may be regarded as a small mine, is owned by E. R. Clingan and is located in sec. 2, T. 18 N., R. 6 E. A section of the bed at this place shows 54½ inches of coal, excluding partings. The three characteristic benches are present, the lowest having a thickness of 24 inches, the middle of 7½ inches, and the uppermost of 23 inches.

Diamond-drill prospects.—In addition to the above prospecting, more or less diamond-drill boring has been done on the high plateau west of Belt Creek, in order to ascertain the thickness of the coal beds in different parts of property owned by large mining companies. No logs of these borings were obtained.

SAND COULEE MINES.

GENERAL STATEMENT.

Three large coal companies are now operating along Sand Coulee and its tributary canyons in the vicinity of Stockett. These are the Cottonwood Coal Company at Stockett, and the Nelson and Gerber coal companies at the town of Sand Coulee. In addition there are a number of prominent individual producers; those deserving especial mention are the Mount Oregon Coal Company and the owners of the Dahn, Brown, and Stainsby mines. This locality was the second to receive attention in the development of the coal resources of the Great Falls field, and at present is the largest producing district of the entire field and one of the largest in the State. Branch railroad lines connect Stockett and Sand Coulee with the Neihart branch of the Great Northern Railway at Gerber station, and a large amount of coal is shipped from these towns to Great Falls and also some to more distant points along the Great Northern main line both to the east and west. The location of the mines is shown on Pl. II; sections of the coal beds are shown on Pl. X.



Thickness of coal shown to right of sections Thickness of waste shown to left of sections

Vertical scale, 1 inch=5 feet

SECTIONS OF COAL BED IN SAND COULEE DISTRICT, MONTANA.

MINES OPERATED.

Cottonwood Coal Company mine.—The mine operated by the Cottonwood Coal Company, which is owned by the Great Northern Railway, is located at Stockett, where the company has extensive holdings. Five mines have been opened since 1898—Nos. 1, 2, and 3 in 1890; No. 4 in 1900; and No. 5 in 1903. All are in sec. 36, T. 19 N., R. 4 E., mine No. 1 in the eastern part, No. 2 in the SE. ¼ SE. ¼, No. 3 in the NE. ¼ SW. ¼, No. 4 in the NW. ¼, and No. 5 in the NW. ¼ NW. ¼. This company has carried on extensive mining operations from the opening of the first mine in 1898. At present Nos. 1, 2, 3, and 4 are abandoned. The thickness of the coal bed worked in mine No. 5 (Pl. XI, *A*) is from 5 to 10 feet, not including partings. Four benches of coal are present in this mine, the lowest having a thickness of 15 inches, the next higher 73 inches, the third 22 inches, and the fourth and top bench 10 inches. Only the first and second benches, however, are mined. The bed worked has a bone roof and clay floor. It lies nearly horizontal, dipping slightly to the north. A graphic section showing the thickness of the benches and bone partings is given in Pl. X, No. 62. The coal contains sulphur in characteristic nodular form.

The Cottonwood Coal Company's mine has probably the best-equipped plant in the Great Falls coal field. It is provided with modern appliances for furnishing air, light, and water, both to the plant and to the underground workings. The impurities found in the different benches of the coal bed are sufficient to make it necessary to clean the coal before it can be placed on the market, and this is done by a dry process which separates the sulphur nodules and the bone from the coal.

The coal is carried from the mine in pit cars of a capacity averaging about 1½ tons. After being weighed on an automatic scale it is dumped by a cross-over tipple above a bar screen, with spaces between the bars 2 inches wide. This screen separates out the smaller pieces of coal, which constitute about 30 per cent of the total, allowing them to fall on a shaking screen having 1-inch round perforations. The slack passes through the screen and is loaded directly into railroad cars or taken to the boiler room by means of a wire-rope conveyor. The coal that passes over the shaking screen slides into a hopper from which it is fed into an elevator that carries it to the top of the building.

The coal that passes over the bar screen falls upon a traveling belt 4 feet 6 inches wide and 26 feet long. Men stationed on either side remove from this belt any large pieces of slate or other foreign matter such as machine picks, car couplings, or sprags, and throw them into a rock elevator. The belt is operated by a clutch, so that in case a large quantity of impurities appear it can be thrown out of gear, and all the impurities can be removed before the coal goes on. The belt delivers the coal to rollers, which reduce it to a size not exceeding 4 inches in largest dimension. It is necessary to reduce the coal to this size in order to detect and remove the sulphur balls present. The rollers are of removable-tooth style, 36 inches in diameter, 48 inches wide, and revolve 75 times per minute.

From the rollers the coal is elevated by a continuous elevator having buckets with a capacity of 110 pounds of coal when level full, operated at a speed equivalent to 200 tons per hour. The capacity of the fine-coal elevator is 90 tons per hour, giving a combined elevating capacity of 290 tons per hour, or 2,900 tons per day of ten hours, an amount which, added to the slack separated out by the shaking screen, gives a total capacity of 3,200 tons per day.

The coal raised by the elevators is evenly divided over an inclined shaking screen 5 feet wide and 46 feet long, whose plates have 1, 1½, 2, 2½, and 3 inch round perforations which separate the coal into slack, pea, nut, stove, egg, and broken sizes.

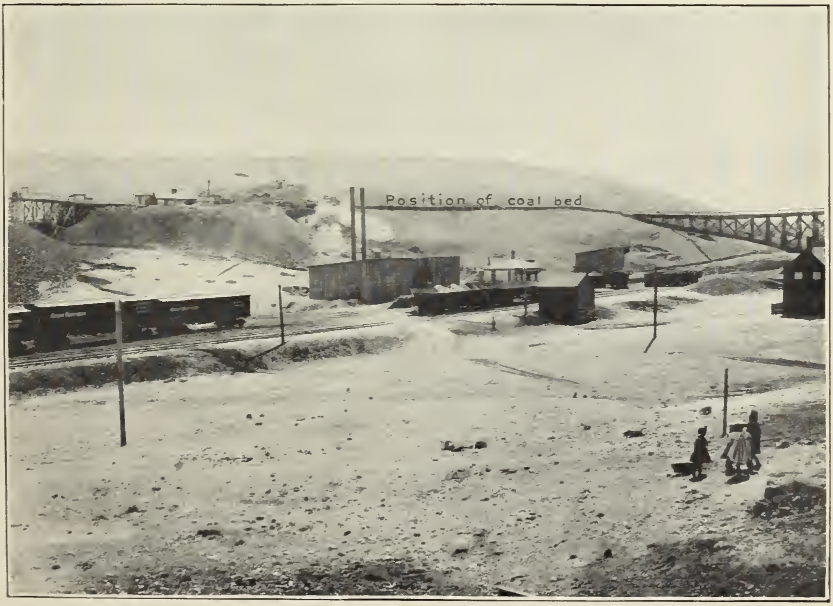
The slack resulting from the breakage of the coal is clean, and, not needing any further preparation, it descends through a hopper to the top strand of a conveyor, which carries it directly to the mixed-coal bin. The other sizes are fed by means of other hoppers into spiral separators which separate out the greater part of the impurities by means of centrifugal force and gravity. These impurities pass either to the lower strand of the conveyor, being taken thence to the rock elevator, or from one set of spirals to the bins by means of chutes, which gives an opportunity to repick the refuse by hand and save any coal that may still remain. The refuse is finally loaded into railroad cars and used for the purpose of widening banks along the railroad.

The coal from the spirals drops onto two picking bands 4 feet wide and 50 feet long, which convey it to the mixed-coal bin and give an opportunity to pick out by hand any impurities not already removed. From one set of the spirals inclined chutes carry the coal into bins for loading straight sizes, any remaining impurities being removed by hand while the material is on the chutes.

On account of the slight difference in specific gravity of coal and bone, the spirals are adjusted so as to retain only the slate and flat sulphur balls, leaving the bone to be removed by hand. The round sulphur balls, which on account of their shape are the first to leave the spirals and go with the coal, also have to be removed by hand.

The rock elevator, having continuous buckets 12 by 30 inches in size, elevates the impurities into a bin, from which they are loaded into a 6-ton car and hoisted by a pair of gear-tailed rope engines with 10 by 18 inch cylinders to the top of the adjoining hill and dumped automatically.

A. COTTONWOOD COAL COMPANY'S MINE NO. 5, NEAR STOCKETT, MONT.



B. NELSON COAL MINE AND PLANT AT SAND COULEE, MONT.

The machinery of the entire plant is driven by a double engine with 13 by 18 inch cylinders, running 150 revolutions per minute.

The percentage of refuse in the various sizes after being treated in the above-described process is stated below:

Refuse remaining in coal at Cottonwood Coal Company's mine, Stockett, Mont.

	Per cent.
Pea	4
Nut	3
Stove	3
Egg	2
Broken	1
Mixed	2.5

Of 2,000 tons of mine product daily dumped into the breakers, 200 tons of the various impurities are removed, and these impurities do not contain on an average over 1 per cent of coal.

For greater detail concerning the breaker used at this plant, including diagrams, the reader is referred to a report by Lewis Stockett,[a] of Stockett.

Nelson mines.—The Nelson mines, the oldest operated in the Sand Coulee basin, are located at the town of Sand Coulee (Pl. XI, *B*). There are two mines; No. 1 is situated on the east side of Sand Coulee, and No. 2 is on the west side, a short distance below the town. Mine No. 2 was first opened by Charles Locery in 1905 and was later sold to the Nelson-Jenks Coal Company. It is not being worked at the present time. Mine No. 1 was extensively worked by the Cottonwood Coal Company before that concern moved to its present location at Stockett. Operations were begun by the Nelson Coal Company at this mine in 1903, and since then the property has been worked continuously. The main entry has been driven in an easterly direction to a distance of about 3,000 feet from the outcrop, and the total acreage of the underground workings is considerable. The coal-bearing rocks at this mine are locally disturbed, the miners having encountered numerous rolls; and in places the coal is entirely absent. The bed ranges in thickness from 6 to 9 feet. It lies nearly level, with a general but low dip to the north, and is composed of benches like those worked at the Gerber mine, described below. The lower bench has a thickness of about 1 foot 6 inches and the upper of about 7 feet 6 inches (50). Between the two is a layer of dark-colored bone 6 to 10 inches thick. The coal of both benches is clear, firm, and noticeably free from foreign material. The sulphur is present in the usual form, but is not abundant. A layer of dark-colored shale 8 inches thick forms the roof. It is overlain by another bench of coal which is not mined at present. The floor consists of dark-colored shale.

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[a] Stockett, Lewis, A bituminous coal breaker in Montana: Min. World, vol. 20, March 26, 1904.

The company employs about 175 men, who work continuously, and in general the plant is very well equipped for handling coal. Ventilation is furnished by a 12-foot fan, and the water is taken out by three large pumps. The coal is machine mined, by the pillar and block system, and is cleaned and assorted into different sizes by means of a 20-foot picking table and a 44-foot shaking screen. Horse haulage is employed.

Gerber mine.—One of the three large mines in the Sand Coulee district is owned by the Rock Springs or Gerber Coal Mining Company. It is located on the west side of Straight Coulee, a tributary to Sand Coulee, about half a mile south of the town of Sand Coulee, in the NE. ¼ sec. 23, T. 19 N., R. 4 E. The mine was opened in 1890 and has been worked continuously since that time. A large force of men is employed and the underground workings are extensive. Though slight local dips are more or less common, the coal bed lies nearly level, dipping only slightly to the north. It is from 6 to 9 feet thick, including partings. It is believed that the coal worked comprises the lower part of the coal bed as exposed in certain parts of this mine and at other places in the Sand Coulee district. Two benches are present—a lower, which has a thickness of about 2 feet, overlain by 2 to 6 inches of dark-colored bone, followed by an upper bench 4 to 7 feet thick (46, 47, 48). Above the upper bench worked there is in some places a coal bed 38 inches thick (55). The coal of all benches is firm, clean-looking, and noticeably free from bony partings. Sulphur, in characteristic nodular form, is present in considerable abundance. The roof consists of a strong dark-colored shale and the floor is a firm, compact clay. A few rolls occur at different places in the bed, but in general it is not much disturbed.

The Gerber Mining Company has a well-equipped plant, with the usual modern appliances for handling coal. There is considerable water in the mine, a portion of which is taken by steam pumps to a reservoir outside the mine, the remainder being pumped to a large tank on the hillside, from which the boilers are supplied. The tipple is located about 600 feet from the mouth of the mine at the end of the railroad. The coal is all machine mined, the bed being worked by the room and pillar system. The coal is fairly free from impurities, and such as exist are taken out by hand picking in the mine and screening at the tipple, no elaborate process being employed. The haulage is effected by means of horses and a small donkey engine. A 12-foot fan furnishes sufficient air to keep the mine well ventilated. Most of the output is shipped to points north, east, and west, local sales being small.

Mount Oregon Coal Company mine.—The Mount Oregon Coal Company mine, which is the largest of the smaller mines in the Sand Coulee district, is located near the town of Sand Coulee in the SE. ¼ sec. 14,

T. 19 N., R. 4 E. This mine is at present worked by Thomas Mokko, and was opened in the spring of 1902. The bed worked has a thickness of about 8 feet. It consists of two benches, a lower bench 30 inches thick, overlain by 3 inches of clay, followed by 63 inches of coal, constituting the upper bench (76).

The main entry extends several hundred feet from the outcrop, with numerous side entries. In working the bed the room and pillar system is carried out. Sufficient provision has been made for the proper ventilation of the underground workings and the water is taken out by a gravity system. The haulage is effected by horses, and a coal bin of 20 tons' capacity is located at the mouth of the mine. The impurities are removed by hand picking and screening. The company employs 18 men and has a daily output of about 45 tons.

Dahn mine.—The Dahn mine, located at Sand Coulee, in the northeast corner of sec. 13, T. 19 N., R. 4 E., is another of the smaller mines of this district. It was first opened in 1890, and has been worked intermittently up to the present time, changing hands several times in the interval. The coal bed underlies a hill covering about 20 acres. Most of the coal in this hill has been worked out. At present the output is 10 to 15 tons a day and only a few men are employed, but prior to 1903 the mine was operated in a more extensive way, 40 to 50 men being employed, with an output of about 100 tons a day.

The coal is between 13 and 14 feet thick. Three benches are present; the lowest is 3 feet thick, the middle 7 feet, and the uppermost 3 feet 2 inches. Between the lowest and the middle bench there is a 2½-inch layer of bone, and above the middle bench a 10-inch layer of shale (54). Only the lowest and middle benches are worked in the Dahn mine. The mine has a shale roof and floor.

Brown mine.—A small coal opening owned and operated by William Brown is located in the SW. ¼ SW. ¼ sec. 18, T. 19 N., R. 5 E. The main entry extends about 500 feet from the outcrop, with two small entries on either side. The mine has been worked for only about two years. Although the beds are nearly horizontal, they are considerably broken and disturbed, making progress slow. The coal is about 7 feet thick, divided into three distinct benches, the lowest 3 inches, the middle 10 inches, and the uppermost 6 feet (56). Shale forms the roof and floor. The output is very small, and operations are carried on only during the winter months.

Stainsby mine.—On the west side of Cottonwood Coulee, about 2 miles below Stockett, near the center of sec. 19, T. 19 N., R. 5 E., is a small mine owned by William Stainsby. Two men are employed, and a small amount of coal is taken out. The bed has a thickness of 12 feet, not including partings, which are about 22 inches thick. There are four benches of coal in all—the lowest 1 foot 5 inches thick, the next higher 5 feet, the next above that 2 feet 2 inches, and the top bench 3 feet 6 inches (59). The coals of the different benches do not appear to vary materially in quality, except that the top bench contains an unusually large amount of sulphur in the characteristic nodular form.

ABANDONED MINES.

In addition to the above-described mines there are in the Sand Coulee district three abandoned openings, known as the Mitchell, McKinsey, and Sarzin mines (Pl. X, 63). These are all small and of minor importance. A number of diamond-drill prospect holes have been sunk by some of the larger coal companies holding property in the immediate vicinity.

SMITH RIVER MINES.

GENERAL STATEMENT.

In the bluffs bordering Smith River and its tributaries, Hound Creek and Ming Coulee, the coal-bearing zone is exposed at many places. Coal has been mined intermittently throughout this district for more than twenty-five years, and within the last decade considerable prospecting has been done in order to ascertain the extent of the bed. Several small mines are now operated, and there are a few abandoned mines from which coal is occasionally taken. Those worked are the Carville, Gibson, Patterson, Bickett, and Love mines, which have a combined annual output of only a few hundred tons. The locations of the prospects and mines are shown on Pl. II; sections of the coal beds are shown on Pl. VIII.

MINES OPERATED.

Carville mine.—The Carville mine, situated on the west side of Hound Creek, in the SW. ¼ SE. ¼ sec. 24, T. 17 N., R. 2 E., is one of the largest in the Smith River district. Coal has been taken out at this place for about seven years. The main entry extends 375 feet west from the outcrop, with a side entry to the south 75 feet long and 40 feet wide, branching from the main entry 90 feet from its mouth. On the north side of the main entry there is another side entry with four large rooms. This mine is not operated in an extensive way, but it is worked continuously, the total annual output being about 1,800 tons. It supplies coal to ranchmen throughout a considerable territory to the south and west. The bed mined is 5 feet 6 inches thick with no appreciable partings. The lower 6 inches of coal is dull looking and in places bony, but it is firm and as a fuel gives good satisfaction. Above this bed there is a bright coal said to be suitable for blacksmithing, which contains numerous iron-pyrite nodules. The thickness and character of the bed remain relatively uniform throughout the workings. The rocks at this place dip slightly to the north and west and are little disturbed.

Gibson mine.—The Gibson mine is located in the extreme southeast corner of sec. 24, T. 17 N., R. 2 E., on the east side of Hound Creek, opposite the Carville mine. It is operated only during the fall and early winter months, and the annual output is about 1,200 tons. The bed worked is slightly thicker than that exposed in the Carville mine, measuring 5 feet 10 inches (69). The upper 2 feet is a bright, firm-looking coal. Beneath this member is a dull bony coal 10 inches thick, followed by 46 inches of dull-looking coal which is said to burn well and as a domestic fuel is in general satisfactory. The main entry extends for about 300 feet at right angles to the face of the bluff. It has two large rooms on the north and one side entry on the south extending diagonally from the main entry to a distance of about 430 feet. This entry is cut across by another side entry, which leaves the main entry at right angles near the back end. The rocks lie nearly horizontal, dipping slightly to the northwest, and are not badly disturbed. The mine is worked by the room and pillar system and little difficulty is experienced with water.

Patterson and Rice mines.—The Patterson mine is situated high in the bluffs on the east side of Smith River, a short distance above the mouth of Hound Creek. The first opening was made in 1903, and the main entry now extends to a distance of 150 feet. A short distance to the east is located the Rice mine, from which, it is said, coal was taken nearly twenty-five years ago. The bed mined has a total thickness of 4 feet 10 inches (78) and the coal appears to be of good quality.

Bickett mine.—On the north side of Ming Coulee, about 1¼ miles above the Eden creamery, a small tonnage of coal is extracted from the Bickett mine. The coal zone or bed is about 18 feet thick and dips at a small angle to the northwest. The upper 10 feet does not contain workable coal, but below this there are two benches of about equal thickness, separated by 8 inches of bone (66). Freshly exposed surfaces of both benches exhibit bright, firm coal. The base of the lower bench, however, contains considerable sulphur in nodular form. The floor and roof of the mine are composed of clay and shale, respectively.

Love mine.—The Love mine consists of a small opening in the bluffs on the south side of Ming Coulee about one-half mile above the Eden creamery, in the E. ½ SE. ¼ sec. 31, T. 18 N., R. 4 E. It has been worked in a desultory way for the last ten years, but only a small amount of coal has been taken out and the mine is poorly developed. The coal bed is unusually thick at this place, measuring over 8 feet, and though the rocks are more or less broken at the surface, it is believed that an entry driven some distance into the hill would encounter the coal undisturbed. The coal zone shows the usual variation, both in number and thickness of coal beds. Four different benches were recognized, of which only the first and second, counting from the base, are mined. The lowest bench is 14 inches thick. It is underlain by bone containing thin streaks of coal and resting on clay. Above the lowest bench of coal there is 1½ feet of bone, followed by 3 feet of coal constituting the upper bench mined. This coal is overlain by 8 inches of bone, forming the roof of the mine. Above the roof there are two coal benches, the lower 18 inches and the upper 3 feet thick; they are separated by 10 inches of bone (65).

PROSPECTS.

In addition to the above-described mines the Smith River district contains a number of prospects, some of which exhibit coal of workable thickness. One opening of this character, owned by Mr. Hoag, is located in the northwest corner of sec. 31, T. 17 N., R. 3 E., and there are others in this immediate vicinity. The location of prospects and mines in this part of the Sand Coulee basin is shown on Pl. II.

OTTER CREEK AREA.

LOCATION AND EXTENT.

The Otter Creek area, which is located southwest of Geyser, extending along Otter Creek for a distance of about 10 miles, lies mainly in T. 17 N., Rs. 8 and 9 E., and includes a small portion of T. 16 N., R. 9 E. The southern limits of the area are definitely marked by the outcrop of the coal, along which a sufficient number of prospect pits occur to indicate its workable character; but to the east, north, and west the extent of the coal can only be inferred from a study of a comparatively small number of exposures. To the east the last exposure of coal of workable thickness is found on the east side of Avoca Creek, at the Chamber Brothers mine. A quarter of a mile farther east, in a small tributary of Avoca Creek, the Meredith prospect shows that the coal of this horizon is not only of less than a workable thickness, but also of inferior quality. Still farther east, in another tributary of Avoca Creek, 1½ miles distant, prospects show that only a few inches of coaly shale occur at the coal horizon. From these prospects and natural exposures of the coal to the east it is assumed that the eastern limit of the Otter Creek area must lie somewhere between the Chamber Brothers mine and the Meredith prospect.

Nor can the northern extension of workable coal be more than approximately located. As previously stated, the coal-bearing rocks of this general vicinity dip gently northeast, passing beneath the overlying Colorado shale, and exposures are therefore few. At the mouth of Williams Creek, however, that stream has cut sufficiently deep to expose the coal bed, which is not of workable thickness. Northwest of this place, on either side of Otter Creek, where the coal is poorly exposed, the bed consists of only a few inches of coaly shale containing thin streaks of coal. On the east side of a small tributary of Little Otter Creek, about 2 miles south of Mann, there are two prospects which demonstrate that the coal horizon shows mainly impure coaly shale. From this evidence it seems highly probable that coal of workable thickness does not continue beyond a line extending northeastward from the coal exposures on the ridge between the Chamber Brothers mine and the Meredith prospect nearly to the mouth of Williams Creek, thence westward along the south side of Otter Creek nearly to Little Otter Creek, thence southward to the vicinity of the Nullinger mine. The limits of the area are shown in Pl. II; sections of the coal beds are shown on Pl. XII.

CHARACTER AND THICKNESS OF COAL BED.

The Otter Creek area is underlain by one bed of coal which ranges in thickness, as indicated by exposures, from 3 to 6 feet; the maximum thickness, however, in the center of the basin probably exceeds 6 feet. The coal generally occurs in two benches, although at one mine three distinct benches were observed. The maximum thickness of workable coal is 4 feet, as shown by the section at the Nollar mine, where it occurs in one bed with no partings. At other places, wherever two benches are present, the lower is generally the thicker and contains the better coal.

The parting between the two benches is commonly bone. At the mine where three benches occur their total thickness is 2 feet 3 inches. It is difficult to give an average section of the coal bed in the Otter Creek area, for only one mine has been opened which may be regarded as representative of the coal in the central part. This mine, owned by Mr. Nollar, shows a total thickness of 4 feet, as above stated. It is probable that over a considerable area the coal retains this thickness, possibly increasing somewhat, but throughout the marginal portions it doubtless becomes thinner.

DEVELOPMENT.

GENERAL STATEMENT.

The coals of the Otter Creek area have not been mined to any considerable extent. Though coal has been taken out of different openings for a number of years, the area as a whole is practically undeveloped. The Billings and Northern Railroad now being constructed will pass near the northern limit of the field, thus affording transportation facilities. At the present time only three small mines are worked—the Nollar, Nullinger, and Chambers mines. Of these only the Nollar is of sufficient size to be regarded as a factor in the production of coal.

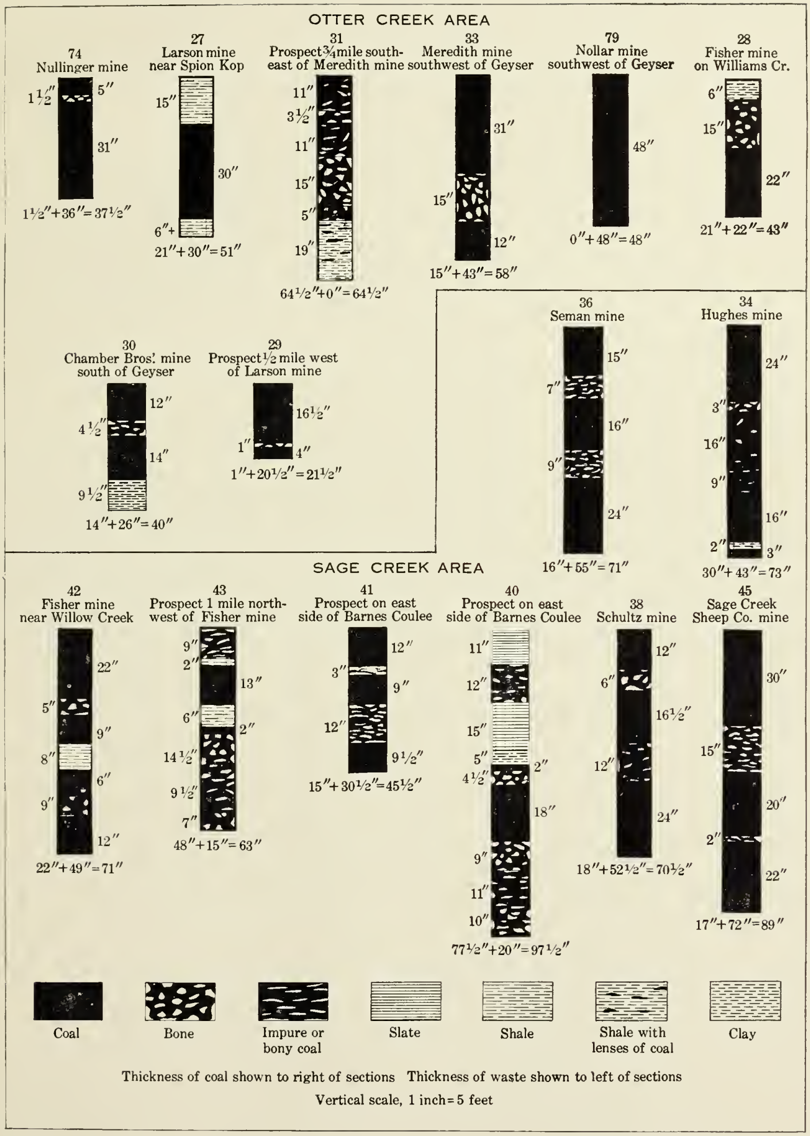
The locations of mines and prospects in the Otter Creek area are shown on Pl. II; sections of the coal bed are shown in Pl. XII.

MINES OPERATED.

Nollar mine.—The Nollar mine is situated at the base of the bluffs on the west side of Otter Creek in the NW. ¼ sec. 29, T. 17 N., R. 9 E. The mine was first opened in 1902 and during the four years of its operation the total output has not exceeded 300 tons. It is not worked continuously, but a few tons of coal are kept on hand to supply a small local trade. The coal occurs in what is apparently one bench 4 feet thick (79), in which no partings of appreciable thickness were observed. The coal is bright and firm, and on close examination shows fine banding on the surface. It contains the characteristic sulphur nodules found in other portions of the field. The entry extends 275 feet from the outcrop in a southwesterly direction. The direction of the main entry at this place is not at right angles to the dip, which here is about due north, but at a slightly greater angle in order to make the entry gradually rise, thus obtaining better drainage. Two side entries extend at right angles from the main entry, one about 80 feet and the other about 200 feet from the face. Each is 75 feet long and is provided with rooms parallel to the main entry. Opposite the first entry to the south there is a front entry leading northward from the main entry; this is provided with a large room nearly 50 feet long. From the end of the second entry to the south there is a narrow cross entry, which extends parallel to the main entry, past the south end of the first entry to the south and thence to the surface.

Chamber Brothers' mine.—Coal is taken during the winter months from the Chamber Brothers' mine, which is located in the NE. ¼ of sec. 4, T. 16 N., R. 9 E., on the east side of West Fork of Avoca Creek. This mine was opened in 1903 and at present has an entry which extends nearly due east for about 125 feet from the face. The coal, which is 2 feet 2 inches thick, is separated into two benches, the lower 14 inches and the upper 12 inches thick. Between the lower and upper benches is a 4¼-inch bed of coaly material. Above the upper bench there is 17 inches of light bluish-gray clay, forming the roof, overlain by dark shale which contains thin streaks of coal. This member is followed by a gray massive sandstone. The floor of the mine consists of dark-colored clay. A complete section is given in Pl. XII, No. 30.

Nullinger mine.—The Nullinger coal mine, situated on the east side of a small tributary of Little Otter Creek, in the SE. ¼ sec. 21, T. 17 N., R. 8 E., is also a very small mine, at the present time furnishing coal



SECTIONS OF COAL BED IN OTTER CREEK AND SAGE CREEK AREAS MONTANA.

for only a few ranches near by. The coal bed has a thickness of 3 feet, and is separated by a 1½-inch layer of bone into two benches (74). It is a bright and firm-looking coal, which doubtless warrants more extensive development. The entry has a pitch of about 60° and extends for about 100 feet from the face in a northeasterly direction. at considerably less than a right angle to the direction of the dip, which is here nearly north.

ABANDONED MINES.

There are three small abandoned mines in the Otter Creek area, two at the mouth of Williams Creek. The one on the south side of the creek is known as the Larson. On it several openings have been made. The opening nearest the road, from which a sample was taken, has an entry 50 feet long. Here the total thickness of the coal is 28 inches, with an appreciable amount of foreign material. About 200 feet east of this opening there is another mine which is said to extend 150 feet into the hill. This was flooded, rendering it impossible to examine the underground workings. About 150 feet still farther east and at a slightly higher level there is another opening with an entry 135 feet long. In excavating this entry a dike of intrusive material at 60 feet from the surface, trending south-southwest, was encountered, and the remainder of the entry was excavated along one side of this dike. The coal in this entry is about 2½ feet thick and is overlain and underlain by compact gray shale. A graphic representation of the section is given in Pl. XII, No. 27.

About 500 feet farther east on the same side of Williams Creek another small opening exhibits a coal bed similar to the one just described.

North of Williams Creek, at the mouth. is the Fisher mine, in which the coal is 22 inches thick. The bed is overlain by 15 inches of bone, followed by 6 inches of coaly shale, above which 15 feet of massive gray sandstone is exposed. A graphic representation of this bed is given in Pl. XII, No. 28; No. 29 represents an exposure of the same bed in a railroad cut one-half mile farther west.

SAGE CREEK AREA.

LOCATION AND EXTENT.

The Sage Creek area, situated in the eastern part of the Great Falls coal field, a few miles south of Stanford, in the vicinity of Skull Butte, lies mainly in Tps. 15 and 16 N., Rs. 11 and 12 E., but embraces small portions of Tps. 15 and 16 N., R. 13 E. The area described encircles Skull Butte, where the dome-shaped uplift exposes rocks older than the coal-bearing measures. This area ranks second in the field in point of size, being slightly larger than the Otter Creek area and considerably smaller than Sand Coulee area. The southern limit of the Sage Creek coal area is definitely marked in most places by the outcrop of the coal, but to the north and to a certain extent to the east and west, the limits of the workable coal must be inferred from geologic evidence. In Barnes Coulee, a tributary of Spring Draw, which is the easternmost locality at which the coal is exposed within the area investigated, the coal bed thins from more than 7 feet on the west side of the coulee to less than 3 feet on the east side, in a distance of less than half a mile. The relative percentages of shale and coal change rapidly in this distance, the former predominating on the east side of the coulee. This rapid change toward the east in both the thickness and the quality of the coal in Barnes Coulee, together with the apparent absence of workable coals for several miles farther east, is regarded as sufficient evidence for placing the eastern limit of the Sage Creek coal area not far beyond this coulee.

To the northeast, farther down Sage Creek valley, where the coals are covered by an increasing thickness of overlying rocks, a number of diamond-drill prospect holes have been bored in order to ascertain the thickness of the coal in this direction. The results of these drillings have not been made public, but in some localities the drilling has been followed by shafting, which indicates that a bed of workable thickness was found. The northern border of this area is arbitrarily placed a short distance beyond the Billings and Northern Railroad from the eastern limit of the district to Stanford, thence westward nearly to Surprise Creek, and thence southwestward to the coal outcrop in the vicinity of Hazlett Creek.

On Hazlett Creek, near the western edge of the area, the coal has been prospected at a number of places. Here the bed is barely of workable thickness and is very shaly. About 3 or 4 miles farther north, on small tributaries of Surprise Creek, the coal bed is represented by only a few inches of impure coal, associated with coaly shale. The same is true on Dry and Shannon creeks, farther west. From the above considerations it seems probable that the western limit of the area underlain by workable coals in the Sage Creek basin lies somewhere between Hazlett and Surprise creeks. The extent of the Sage Creek area and the location of the mines and prospects are shown on Pl. II; sections of the beds are shown in Pl. XII.

CHARACTER AND THICKNESS OF COAL BED.

So far as known there is only one coal bed in this area. Its thickness, including partings, ranges from 6 to 18 feet. Within this thickness of beds, deposited under coal-forming conditions, the aggregate of the coal ranges from 2½ to 7 feet. The coal usually occurs in the form of three distinct benches, which are generally recognized by miners in the district. The lowest bench is about 2 feet thick and is regarded as the best. Above this is commonly a 2 to 6 inch parting, overlain by a middle bench 12 to 16 inches thick. Next is generally 1 to 6 inches of bone, followed by the uppermost bench of coal, which ranges from 1 to 2 feet in thickness. The coal is usually covered by 1 or 2 feet of dark-colored shale, which forms the roof of the mine. Above the shale there are in many places impure coaly layers interbedded with brown and black sandy leaf-bearing shale having a thickness of several feet. The next member in ascending order is a gray massive sandstone ranging in thickness from 20 to 60 feet. In the outer portion of the area the base of this sandstone locally forms the roof of the mine.

DEVELOPMENT.

GENERAL STATEMENT.

The coals of the Sage Creek area have not been extensively worked. Coal has been mined in this vicinity for many years, but owing to the lack of transportation facilities the output has never exceeded the amount necessary to supply a small local demand. At the present time mining is carried on at only three small mines, owned by Messrs. Schultz, Seman, and Hughes. The annual output of the Schultz mine is about 1,000 tons; that of the Seman is somewhat smaller. Neither of these mines is well improved. The Hughes mine has only recently been opened.

MINES OPERATED.

Schultz mine.—The Schultz mine, the largest of the three mines now operated in this district, is located in the SE. ¼ SE. ¼ sec. 20, T. 15 N., R. 12 E., on the west side of Spring Draw, a small tributary of Sage Creek. It was opened in 1894, and, according to the best information obtainable, though operations have been continuous, the output of the mine has never been large. The present annual production amounts to 1,000 tons, which is consumed by ranchmen and inhabitants of small towns within a radius of 10 to 15 miles. The coal zone has an aggregate thickness of slightly over 12 feet, but only the coal of the lower half is mined, none of that in the upper part being regarded as of sufficient thickness to be worked. The coal of the lower part occurs in three benches, which have a total thickness of 4 feet 4½ inches, not including the 6-inch layer of bone 1 foot below the top and the 1 foot of bony coal 2 feet above the base. The lowest bench is 2 feet thick and constitutes the most important coal of the mine. It is black, with a dull luster, and contains more or less pyrite in nodular form. The middle bench has a thickness of about 16½ inches and generally has a bright luster. It, too, contains some pyrite nodules. The uppermost bench is about 12 inches thick and is generally more or less free from sulphur (38). Immediately overlying this bench in the upper part of the zone is a layer of bone 2 feet thick, which forms the roof of the mine. This is followed by 12 inches of dark sandy shale containing thin beds of coal, which in turn is overlain by 21 inches of coal containing a small percentage of bone. Above this coal there is an 8-inch layer of light-colored sandstone, followed by 6 inches of dark coaly shale which immediately underlies massive gray sandstone several feet in thickness.

Seman mine.—The Seman mine is located in the SW. ¼ SE. ¼ sec. 20, T. 15 N., R. 12 E., a few hundred yards west of the Schultz mine and on the same side of Spring Draw. It is considerably smaller than the Schultz mine and is worked only during the winter months, having a very small output, which rarely exceeds 150 tons a season. Coal has been taken out of this opening for the last decade, but little attention has been given to the proper development of the underground workings.

The coal bed mined here is almost identical with that worked at the Schultz mine, except in the uppermost bench, which appears to be somewhat thicker. Three benches occur; the lowest bench has a thickness of 2 feet and is overlain by 9 inches of bony coal. Above this is the middle bench, which has a thickness of 16 inches and is followed by a 7-inch layer of bone. Next is 15 inches of bright, firm-looking coal, which constitutes the uppermost bench. A complete section is shown in Pl. XII, No. 36. The deposit has the characteristic shale roof and clay floor exhibited in the Schultz mine.

In physical properties the coals of the different benches closely resemble those of the Schultz mine. The characteristic sulphur balls are present, especially in the lowest bench; the middle bench has the usual bright luster, and in practical use these two coals seem to give equal satisfaction. The main entry extends about 400 feet from the face in a meandering but westerly direction. About 200 feet from the mouth of this entry a side entry extends at right angles, approximately 30 feet to the south.

Hughes mine.—In 1904 a small mine was opened on the Hughes ranch, on the east side of Willow Creek, in the NE. ¼ sec. 19, T. 15 N., R. 12 E. This mine is about 2 miles northwest of the Schultz and Seman mines, near the southern limit of the Sage Creek area. The total thickness of the bed worked is 5 feet 8 inches, including a 9-inch layer of bony coal 16 inches above the base and excluding a 3-inch bed of true bone 2 feet below the top of the bed. Coal occurs in three benches, as is common in other parts of the area. The lowest bench is slightly thinner than usual, being only about 16 inches thick. This is due to a 2-inch layer of clay that occurs at the base of the bench and separates it from a 3-inch bed of coal not mined at this place. The middle bench is 16 inches thick and is bright and firm, but contains a few thin layers of bone. A 3-foot bed of good-looking coal constitutes the uppermost bench. It is overlain by dark-colored sandy shale, which forms the roof. A graphic section of the bed is given in Pl. XII, No. 34.

ABANDONED MINES.

In addition to the above-described mines, there are in the Sage Creek area four abandoned mines from which considerable coal has been taken during the last ten years. These are the Corwin & McGregor (now owned by Mr. Schultz), the Fisher, the West Fork of Willow Creek, and the Sage Creek Sheep Company mines. Graphic sections of all except the Corwin & McGregor mine are given in Pl. XII, Nos. 42, 43, and 45.

Corwin & McGregor mine.—The abandoned Corwin & McGregor mine, located on the west side of Spring Draw, between the Seman and Schultz mines, was one of the first to be operated in the immediate vicinity, and it has probably been more extensively worked than either of the adjoining mines. At the face of this opening the coal horizon presents the usual succession of beds, but they were too badly weathered to permit accurate measurements of the individual layers, and, as the mine was flooded, the underground workings could not be examined.

The face of the mine presents one unusual feature. The coal in the upper part of the coal bed, as exposed at the Schultz mine, here appears to have reached a thickness of 2½ feet. The percentage of this bed that might prove to be coal when examined on a freshly exposed surface could not be ascertained.

Fisher mine.—Another abandoned mine, known as the Fisher mine, is located on the east side of a low hill of isolated coal-bearing rocks, which occur as an outlier on the south side of the area, in the SE. ¼ sec. 13, T. 15 N., R. 11 E. It has not been worked for a number of years, but to judge from the size of the excavation, considerable coal has been taken out in the past. The bed is not deeply covered nor extensive, comprising at most only a few acres, and for this reason probably the mine was abandoned. It is very doubtful if the deposits are sufficiently extensive to warrant any further development. A section of the face of this opening is given in Pl. XII, No. 42.

West Fork of Willow Creek mine.—At the head of West Fork of Willow Creek there is an abandoned mine from which, apparently, considerable coal has been taken out, but it has caved to such an extent that it was impossible to examine the details of the underground workings. It is located near the southern edge of the coal area, in the NW. ¼ sec. 13, T. 15 N., R. 11 E. A section of the outcrop shows very poor coal in the lower bench (43).

Sage Creek Sheep Company mine.—An abandoned opening on the north side of Skull Butte, in the SW. ¼ sec. 31, T. 16 N., R. 12 E., is known as the Sage Creek Sheep Company mine. A small amount of coal was taken out of this mine, but it has not been worked for several years (45).

PROSPECTS.

Entry prospects.—The Sage Creek area has been considerably prospected for coal. In many of the coulees where the coal is exposed small openings have been made to ascertain the character and thickness of the bed. Some of these prospects have caved so as to obscure the coal bed, but more commonly a good section can be obtained. In Barnes Coulee, a small tributary of Spring Draw on the east, the coal has been opened at five or six places on either side of the ravine. J. D. Barnes has the largest prospect in this vicinity. It is located on the west side of the coulee about 100 feet up the slope, in the SE. ¼ sec. 29, T. 15 N., R. 12 E. An entry has been driven 80 feet from the face, which exhibits over 7 feet of coal distributed through 13 feet of coal-bearing beds. The coal is overlain by gray sandstone and underlain by dark-colored shale.

Directly opposite the Barnes prospect on the other side of the coulee the coal has been opened at five places, the northernmost opening being an entry 15 feet deep which exhibits 4 feet of coal interbedded with considerable bone. About 150 feet south of this prospect another opening extends 120 feet from the face, showing 3 feet of coal. The lower 21 inches, however, is of a very inferior quality.

About 400 feet farther south on the same side of the coulee the entry of another small abandoned mine extends 150 feet from the face. At the mouth the coal bed has a total thickness of 7 feet 2½ inches, with only 18 inches of pure coal near the middle; 9 inches below this and 10 inches above the bottom of the section there is an 11-inch bed of bony coal (40). At the end of the main entry, 150 feet from the mouth of the mine, the section shows 9½ inches of coal at the base, which probably corresponds to the 11 inches of bony coal at the mouth. Overlying the 9½-inch layer of coal is 12 inches of bone, corresponding to the 9 inches of true bone in the section taken at the outcrop. The next member in ascending order at the back end of the entry is a 9-inch bed of coal followed by 3 inches of shale, and this in turn by 12 inches of coal. These three members are believed to be represented in the outcrop section by 18 inches of coal. The sections at the outcrop and at the back end of the entry are shown in Pl. XII, Nos. 40 and 41.

Nearly 300 yards south of this abandoned mine a small prospect shows very bony coal.

A comparison of the sections in these five prospects on the east side of Barnes Coulee with the Barnes prospect on the opposite side indicates not only that the percentage of coal in the bed is decreasing to the east but that the quality of the coal is rapidly becoming inferior in that direction.

Diamond-drill prospects.—Considerable prospecting has been done with the diamond drill in the Sage Creek coal area, mainly to determine the thickness of the coal bed in the northern part of the field, where the gradual dip of the beds to the northward carries it considerably below the surface. Five borings have been made, as follows: The Sage Creek Sheep Company's home-ranch boring, in the SW. ¼ sec. 14, T. 15 N., R. 12 E.; the McComb boring, in the NE. ¼ NE. ¼ sec. 18, T. 15 N., R. 12 E.; the upper Sage Creek boring, in the NE. ¼ NW. ¼ sec. 2, T. 14 N., R. 12 E.; and the Dry Coulee boring, in the SW. ¼ SW. ¼ sec. 20, T. 13 N., R. 12 E. These borings are said to range in depth from 300 to 900 feet, but no definite information regarding the thickness of the coal bed or the depth at which it was penetrated in any particular well could be obtained.

CHARACTER OF COAL.

GENERAL STATEMENT.

The coal of the Great Falls field differs in physical characteristics as well as in chemical composition from those of neighboring fields in Montana and northern Wyoming. As it occurs in rocks of Lower Cretaceous age, it is among the oldest coals in this general region, the nearest contemporaneous deposits being the Cambria coals of the Black Hills and the Lethbridge coals of Canada. It is of the same age as the coal of Judith basin (which in reality is a part of the same field) and is considerably older than the Bull Mountain, Miles City, Sheridan, and Red Lodge coals, most of which are of Tertiary age. In physical properties and chemical composition it shows little regional variation and closely resembles deposits of the same age in Judith basin to the east. It also bears some likeness to the Cambria coals of the Black Hills.

PHYSICAL PROPERTIES.

The coal of the Great Falls field is in general black to grayish black in color, with bands of pitch-black coal running through it. A great part of the coal is dull, but contains thin bands of bright coal which have a vitreous or glassy luster. It is a moderately dense variety of bituminous coal distinctly bedded and characterized by a banded structure, which consists of alternating layers of bright and dull coal parallel to the bedding. The bright bands range in thickness from a mere film to one-fourth of an inch, and usually constitute only a small percentage of the whole, the duller coal greatly predominating. A close examination of the dull bands, which consist partly of mineral charcoal and partly of dull-lustered coal, shows that many of them contain minute lenses of bright coal, giving to the whole a schistose appearance.

The coal usually separates or breaks into blocks that are roughly rectangular in outline, with the face and butt cleat nearly at right angles. Even where fine fragments are separated either by crushing or weathering they are in general rudely prismatic. The face cleat commonly presents a smooth, even surface having a subdued glistening or vitreous luster; the butt cleat has a more irregular surface and a much brighter luster. The fracture of the dull coal is irregular or uneven, but that of the bright coal is small conchoidal. The coal separates more or less easily along the bedding plane, the surface of which at many places exhibits blades of mineral charcoal lying in different directions, the whole giving a fibrous texture and velvet luster. Less commonly the surface of the bedding plane contains remnants of bright-lustered coal adhering to the duller variety. It is under these circumstances that the bright coal exhibits to the best advantage its small conchoidal fracture.

The dull coal is moderately soft and tough; the bright coal is considerably harder and more brittle. The hardness of the former is about 1 and that of the latter about 2.5. The streak ranges from brown to brownish black, seldom black. The coal is more or less sooty and soils the fingers readily. The specific gravity varies considerably in different benches of the same bed; it ranges from 1.30 to 1.70, the average being about 1.40.

As previously stated, sulphur is present in the coal in considerable quantities. It occurs in the form of iron-pyrite nodules which are rudely reniform in outline, although spherical forms are not uncommon. In size these nodules range from that of a pinhead to about 4 inches in diameter, the average being about 1 inch. Their major axes are usually parallel with the bedding, although some smaller nodules are seen at varying angles to that plane. Few of them occur in joint planes. About the nodules the coal shows a foliated or compressed structure, which has probably been developed by the force exerted in the crystallization of the pyrite. Resin is rarely present.

The minable coal is separated into benches by carbonaceous shale or bone and by bony coal. The former appears to be of fairly uniform character throughout the field. It has shaly structure and breaks with subconchoidal fracture. It is grayish black in color, fine grained and homogeneous in character, soft, moderately tough, and has a specific gravity of about 2. It is usually a true parting between the coal benches, separating easily from the coal both above and below. In thickness it ranges from a fraction of an inch to 1 foot, the average being about 3 to 4 inches. In some places it weathers light gray, standing out in strong contrast to the coal.

CHEMICAL PROPERTIES.

During the investigation here reported a number of samples of the coal were taken in different localities for the purpose of chemical analysis. These samples were collected in a uniform manner. A channel was cut perpendicularly across the face of the coal bed from roof to floor, of such a size as to yield at least 5 pounds of coal per foot in thickness of coal bed. All material encountered in this cut was included in the sample, except partings more than three-eighths of an inch in thickness, and lenses and concretions of sulphur or other impurities greater than 2 inches in diameter. The coal thus obtained was pulverized sufficiently fine to pass through a sieve of half-inch mesh, and after thoroughly mixing was divided into quarters, opposite quarters being rejected. This process was continued until the amount was reduced to about a quart sample. The material was then placed in a galvanized can, sealed by adhesive tape, and shipped to the chemical laboratory of the Survey fuel-testing plant at St. Louis, F. M. Stanton, chemist in charge, where the analyses were made.

Analyses of coal samples from Great Falls coal field.

		Sage Creek area.		Otter Creek area.			Sand Coulee area.		
							Belt district.		
Laboratory No		3756	3753	3758	3759	3757	3515	3512	3514
Analysis of sample as received:									
Prox.	Moisture	11.26	9.27	10.18	8.76	13.07	3.51	7.05	6.37
	Volatile matter	25.85	29.57	24.82	25.72	21.79	26.39	25.47	27.55
	Fixed carbon	46.49	45.90	45.25	50.36	43.26	50.60	49.34	45.20
	Ash	16.40	15.26	19.75	15.16	21.88	19.50	18.14	20.88
Ult.	Sulphur	4.56	3.96	3.01	3.91	1.30	3.74	1.67	2.04
	Hydrogen	4.51	4.78	....	4.40	4.23	4.13	4.36	3.92
	Carbon	53.47	58.13	....	58.93	49.95	61.51	58.10	56.14
	Nitrogen	.69	.79	....	.79	.69	.60	.64	.73
	Oxygen	20.37	17.08	....	16.81	21.95	10.44	17.09	16.29
Calories		5,122	5,675	....	5,626	4,639	6,045	5,623	5,481
British thermal units		9,220	10.215	....	10,127	8.350	10,881	10,121	9,866
Loss of moisture on air drying		5.50	4.60	4.60	4.80	6.00	1.60	2.60	2.70
Analysis of air-dried sample:									
Prox.	Moisture	6.09	5.00	5.85	4.16	7.52	1.93	4.57	3.77
	Volatile matter	27.35	31.00	26.01	27.02	23.18	26.81	26.15	28.30
	Fixed carbon	49.18	48.00	47.43	52.90	46.02	51.44	50.65	46.46
	Ash	17.38	16.00	20.71	15.92	23.28	19.82	18.63	21.47
Ult.	Sulphur	4.82	4.15	3.15	4.11	1.38	3.80	1.71	2.08
	Hydrogen	4.12	4.48	....	4.03	3.79	4.02	4.17	3.73
	Carbon	56.57	60.93	....	61.90	53.14	62.51	59.65	57.70
	Nitrogen	.73	.83	....	.83	.73	.69	.65	.74
	Oxygen	16.38	13.61	....	13.21	17.68	9.16	15.19	14.28
Calories		5,420	5,949	....	5,910	4,951	6,094	5,824	5,633
British thermal units		9,756	10,707	....	10,637	8,888	11,058	10,391	10,139
Fuel ratio		1.79	1.55	1.82	1.96	1.98	1.91	1.93	1.64

Analyses of coal samples from Great Falls coal field—Continued.

		Sand Coulee area.							
		Belt district.			Stockett-Sand Coulee district.		Smith River district.		
	Laboratory No	3755	3513	3754	4115	4119	4118	4117	4114
	Analysis of sample as received:								
Prox.	Moisture	9.58	4.62	10.88	6.01	7.49	4.82	6.17	4.54
	Volatile matter	23.24	30.51	20.27	28.43	27.29	27.17	27.03	27.44
	Fixed carbon	52.24	46.14	41.97	51.42	51.44	46.13	52.03	47.95
	Ash	14.94	18.73	26.88	14.14	13.78	21.88	14.77	20.07
Ult.	Sulphur	2.00	3.59	1.79	2.38	2.32	2.84	4.36	4.09
	Hydrogen	4.28	....	3.72	4.46	4.68	4.36	4.43	4.23
	Carbon	58.74	....	47.37	63.61	62.21	56.98	61.62	58.66
	Nitrogen	.67	....	.52	.91	.88	.72	.93	.87
	Oxygen	19.37	....	19.72	14.50	16.13	13.22	13.89	12.08
	Calories	5,518	....	4.301	6,196	6,115	5,578	6.077	5,818
	British thermal units	9,932	....	7,742	11,153	11,007	10,040	10,939	10,472
	Loss of moisture on air drying	5.00	2.10	5.40	2.40	2.60	1.90	2.20	1.70
	Analysis of air-dried sample:								
Prox.	Moisture	4.82	2.57	5.76	3.70	5.02	2.98	4.06	2.89
	Volatile matter	24.46	31.17	21.42	29.13	28.02	27.69	27.63	27.91
	Fixed carbon	55.00	47.13	44.42	52.68	52.81	47.03	53.20	48.79
	Ash	15.72	19.13	28.40	14.49	14.15	22.30	15.11	20.41
Ult.	Sulphur	2.10	3.70	1.89	2.43	2.38	2.90	4.46	4.13
	Hydrogen	3.91	....	3.30	4.33	4.51	4.24	4.25	4.18
	Carbon	61.85	....	50.08	65.17	63.88	58.08	63.02	59.66
	Nitrogen	.70	....	.55	.92	.89	.73	.95	.88
	Oxygen	15.72	....	15.78	12.66	14.19	11.75	12.21	10.74
	Calories	5,808	....	4,546	6,348	6,278	5,678	6,213	5,918
	British thermal units	10,454	....	8,184	11,427	11,300	10,244	11,185	10,654
	Fuel ratio	2.25	1.51	2.07	1.81	1.88	1.70	1.93	1.75

The analysis of each coal sample is given in two forms, one showing the composition of the sample as received at the laboratory, which may be regarded as representing the condition of the coal in the mine, the other showing the composition of an air-dried sample. Ultimate analyses were obtained of all except two samples. The analyses under laboratory Nos. 3756, 3757, and 3754 can not be regarded as representative of the coals of this field, for each of these samples was collected in a shallow entry near the surface, and consequently contained weathered coal. Sample No. 3754 was obtained on the margin of a coal-bearing area, where the coal was recognized in the field to be of a quality too inferior to work.

The coal of the Great Falls field contains on an average about 49 per cent of fixed carbon, 26 per cent of volatile matter, 18 per cent of ash, and 3 per cent of sulphur. Its fuel ratio, obtained by dividing the percentage of fixed carbon by the percentage of volatile matter, ranges from 1.51 to 2.07, with an average of 1.84. The calorific value of the coal is good, ranging in representative samples from about 10,000 to 11,500 British thermal units, the average being 10,750 in an air-dried sample. They are superior in this respect to the coals of Red Lodge, the next largest coal-producing locality in Montana. Their heat value is also considerably higher than that of the coals of the Bull Mountain and eastern Montana fields. The coal does not slack to any appreciable extent on exposure to the air. Certain benches of the coal possess coking properties and formerly a number of coke ovens were operated by the Anaconda Copper Mining Company at Belt. The separation of coking from noncoking coal, however, was too expensive to render the work profitable, and the ovens were abandoned. As a domestic and steam fuel it gives perfect satisfaction and its relative freedom from slacking makes it a good shipping coal.

From the analyses and the physical properties, therefore, the coal of the Great Falls field is regarded as medium-grade bituminous. It is superior in quality to the Red Lodge, Bridger, and Sheridan coals of southern Montana and northern Wyoming, and compares favorably in composition with the Cambria coal of the Black Hills region.

FUTURE DEVELOPMENT.

The Great Falls coal field, owing to its geographic position with respect to other coal fields and the quality of the product itself, is destined to become the most important coal-mining district of north-central Montana. The territory which this field may be expected to supply with coal in the future lies mainly to the north and northwest. To the southeast there are a number of coal localities along Musselshell River, which with the development of proper railroad facilities would probably become large coal-producing districts. Throughout the area bordering the Great Falls coal field on the north different conditions prevail. Here, although coal-bearing rocks occupy extensive areas both to the northeast in the vicinity of Havre and to the northwest along the base of the Rocky Mountain front range, yet from the best information which can be obtained the area underlain by coal of workable thickness is not large nor are the deposits of high grade, so that much of this part of Montana will probably be supplied from the Great Falls field. The Lethbridge coal field, north of the international boundary line, is a large coal-producing district, but with the present tariff of 60 cents per ton and the increasing settlement of this part of the British possessions much of the output will probably be consumed in Canada, leaving a relatively small amount to be shipped into Montana.

A summary of the transportation facilities, present and prospective, has already been given (p. 20). Another factor to be considered in the general development of this region is the unharnessed water power contained in the Great Falls of Missouri River, located a few miles below the town of Great Falls. At present the Black Eagle Falls, one of the smallest and the only one of this series of cataracts which has been utilized, furnishes power for the large smelters owned by the Boston and Montana Consolidated Copper Mining Company, the Royal Milling Company's flour mills, and other minor industries. With the proper utilization of Rainbow, Crooked, and Big Falls, located farther down the river, sufficient power could be generated to supply many more large industrial enterprises. The presence of so large an amount of undeveloped water power within a relatively short distance of the large mining centers, Butte and Anaconda, makes Great Falls a favorable site for smelters.

The Great Falls region was formerly a grazing district and only sparsely populated. Small tracts of land were irrigated here and there along the valleys, but with the growth in population and the increased demand for agricultural produce irrigation began to be more generally practiced along the larger streams, resulting eventually in the construction of several large canals by private individuals or small companies organized among the ranchmen. Extensive operations are now being carried on, both by the Government and by private enterprise, to reclaim larger tracts of land along Sun and Teton rivers and the highland lying between these two streams.

Although the Great Falls district is not at present very thickly settled, it is believed that the increasing railroad facilities, the completion of the Government irrigation projects, which will reclaim thousands of acres of fertile farming land, and the almost unparalleled advantages for the development of water power will combine to cause a rapid increase in population within the next decade. This increase will be attended by an increased demand for coal, both for domestic and steam purposes, and though the coal is only of medium grade and the deposits are not extensive, it is believed that the Great Falls coal field will experience material development within the next few years.

TIMBER.

The area included in this report is essentially a grazing district, with very little timber except along the valleys of the larger streams, where deciduous trees are more or less abundant, and along the hilly zones bordering the mountains, where there is a scanty growth of coniferous forests. The Little Belt Mountains to the south are irregularly forested throughout a considerable part of the uplift, and though there have been numerous fires, large areas of good timber remain. Nearly all the districts containing valuable timber lie inside the Little Belt Mountain Forest Reserve, the location of which is shown on the index map (Pl. I). The most abundant trees growing in the Little Belt Mountains are lodgepole pine, red fir, and Englemann spruce. Of these species the red fir is most extensively used for mine timbering in the Great Falls coal field, much of the supply being derived by rail from the Neihart district of the Little Belt Range. For some of the smaller mines, however, timber is procured in the foothills belt and hauled overland. The fact that all the larger mines are located out on the plains, at some distance from the forested area of the mountains, makes timber an expensive item in mine operations, especially at Stockett and Sand Coulee, which are farthest from the source of supply.

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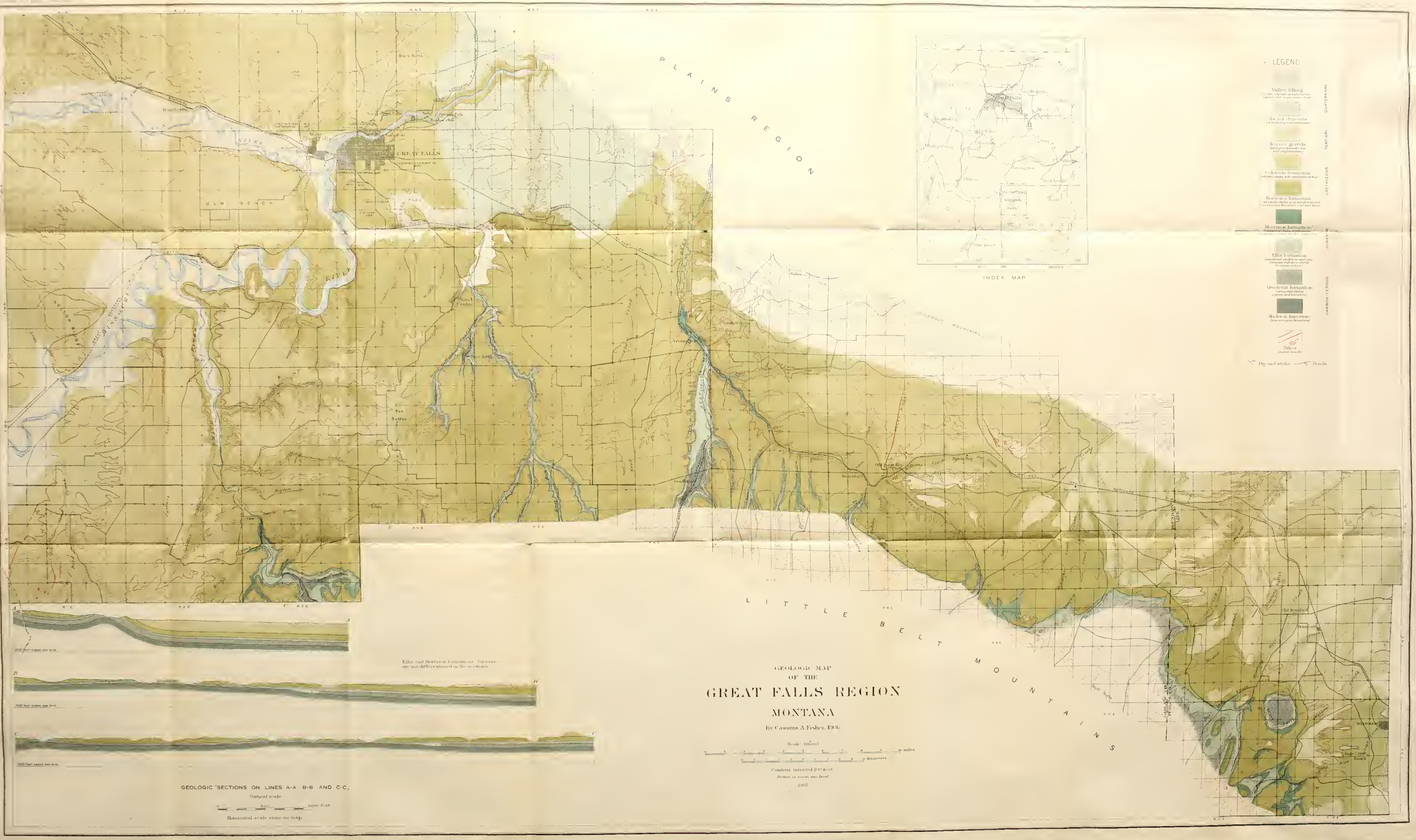


GEOLOGIC MAP
OF THE
GREAT FALLS REGION
MONTANA

By Cassius A Fisher, 1906

Scale $\frac{1}{125000}$

Contour interval 100 feet
Datum is mean sea level

1907

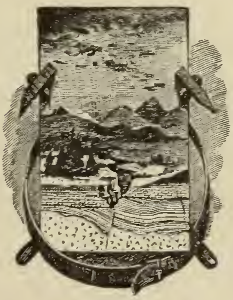
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 357

PRELIMINARY REPORT
ON THE
COALINGA OIL DISTRICT
FRESNO AND KINGS COUNTIES
CALIFORNIA

BY

RALPH ARNOLD AND ROBERT ANDERSON



WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

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The oil fields—Continued.

The oil fields—Continued.

Details of the productive areas—Continued.

ILLUSTRATIONS.

PRELIMINARY REPORT ON THE GEOLOGY AND OIL RESOURCES OF THE COALINGA DISTRICT, FRESNO AND KINGS COUNTIES, CAL.

By Ralph Arnold and Robert Anderson.

INTRODUCTION.

General features of the district.—The Coalinga district is a strip of land about 50 miles in length by 15 miles in width lying along the northeastern base of the Diablo Range in western Fresno and Kings counties, Cal. The region is accessible by rail from the main lines of both the Southern Pacific and the Atchison, Topeka and Santa Fe railroads by a branch line running westward from Goshen to the town of Coalinga. The proved productive territory includes a band 13 miles long by 3 miles wide, lying at the northern end, and a narrow strip along the southwestern boundary. The oil originated in the organic Tejon (Eocene) shales and is accumulated in interbedded sands of the same formation and also in sands of the Vaqueros (lower Miocene), Santa Margarita (upper middle Miocene), and Jacalitos (upper Miocene) formations, the Vaqueros being the principal producer. The wells range in depth from 600 to over 3,300 feet, and penetrate from 20 to more than 200 feet of productive sands. The product varies from a black oil of 14° or 15° Baumé to a greenish oil of 35° Baumé or better. The yields range from 3 or 4 barrels a day for individual wells in the Oil City field to as much as 3,000 barrels a day for the deeper holes in the Eastside field. The total production of the district in 1906 was 7,991,039 barrels; in 1907 it was 8,871,723 barrels, and in 1908 it will probably exceed 12,000,000 barrels. According to the figures for 1907 the district ranks third in production among the oil-producing districts of the State.

Plan of the present report.—During the last half of 1901 and the first half of 1902 George H. Eldridge, of the United States Geological Survey, made more or less detailed examinations of the various California oil districts, with the expectation of preparing a monograph on the oil resources of the State. On his return from field work he wrote a brief résumé of the results obtained, and this was published in "Contributions to Economic Geology for 1902."[a] Later he began the preparation of detailed reports on each field, but his lamented death in June, 1905, cut short this work. In the fall of 1905 the senior author of this report was instructed to complete the work begun by Mr. Eldridge, and by the middle of 1907 detailed reports on all of the oil districts in the counties bordering the coast had been made ready for the press.[b]

The summer and fall of 1907 were spent by the writers in making a detailed geologic investigation of the Coalinga field proper and of the territory south of it as far as the Kings County-Kern County line near Dudley. In order to make the results of this investigation available as soon as possible, it has been deemed expedient to prepare the following preliminary report. This will be followed later by a bulletin containing more detailed descriptions of the conditions, more complete maps, sections, and other illustrations, and chemical analyses and calorific tests of a large number of the oils. The location of the Coalinga district and the other oil fields of southern California are shown in fig. 1.

For the benefit of those using this and other geologic reports on the California oil fields, it must be stated that these publications are intended to be as thoroughly scientific discussions as possible, and that they assume on the part of the reader a general knowledge of the fundamental facts and conceptions on which any searching study of the composition, mineral deposits, and history of the earth must be based. The reports may be criticised as being too technical and as not easily comprehensible by the ordinary reader, but the treatment adopted is the only one possible, because the thorough discussion of the subject involves a certain amount of technical knowledge and the use of exact terms. Explanatory discussions have been inserted wherever it seemed possible to do so without making the reports too bulky or diminishing their scientific value. For explanations of the principles of geology or the meaning of terms the reader is referred to any one of the numerous text-books of geology.[c]

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[a] Eldridge, G. H., The petroleum fields of California: Contributions to economic geology, 1902: Bull. U. S. Geol. Survey No. 213, 1903, pp. 306–321. (The part relating particularly to the Coalinga district is on pages 306–308.)

[b] Eldridge, G. H., and Arnold, Ralph, The Santa Clara Valley, Puente Hills, and Los Angeles oil districts, southern California: Bull. U. S. Geol. Survey No. 309, 1907.

Arnold, Ralph, and Anderson, Robert, Preliminary report on the Santa Maria oil district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 317, 1907.

Arnold, Ralph, Geology and oil resources of the Summerland district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 321, 1907.

Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 322, 1908.

[c] Any of the following, besides various others, will be found useful: Dana, Text-book of Geology; Le Conte, Elements of Geology; Chamberlin and Salisbury, Geology (3 parts); Geikie, Text-book of Geology.

Acknowledgments.—The writers wish to acknowledge their indebtedness to the late George H. Eldridge for notes collected by him during his examination of the field. Acknowledgment is also due to other previous workers in the field, among whom are W. L. Watts, Frank M. Anderson, John H. Means, and H. R. Johnson.

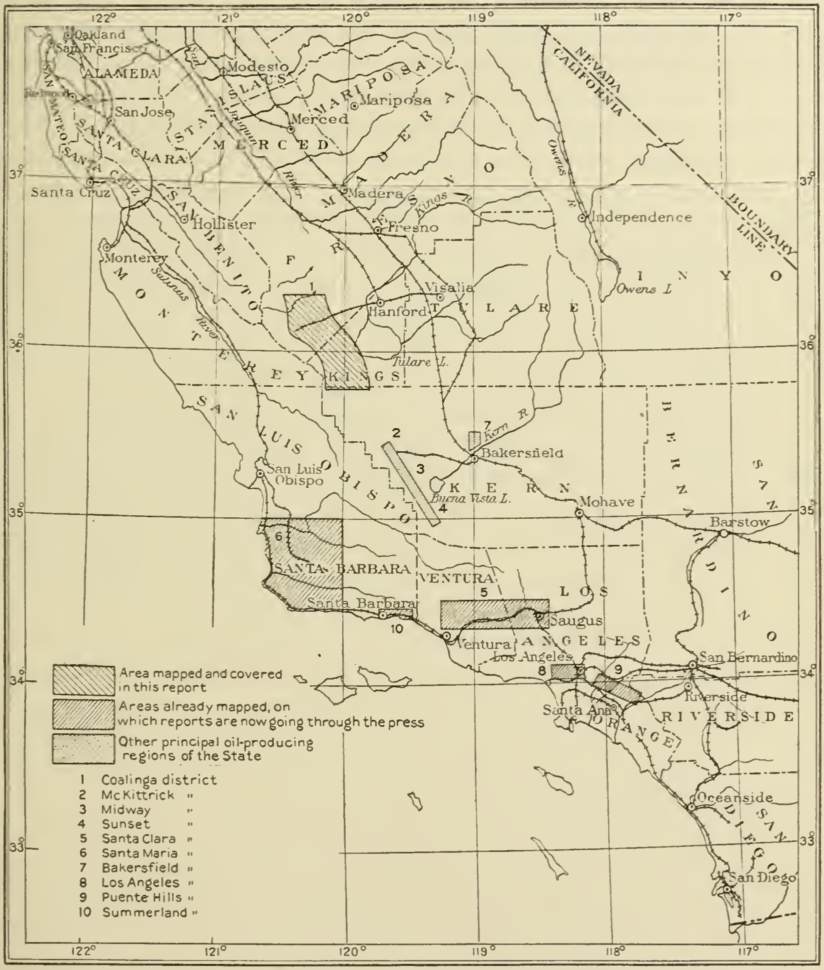

FIG. 1.—Index map of a part of southern California, showing location of the Coalinga oil field and of the other productive oil fields of the State.

The value and accuracy of a report like the present one, including as it does a discussion of the geology of developed territory, depends largely upon the amount and accuracy of the well data available for use in its preparation. Certain facts may be gleaned from a critical examination of the surface outcrops in any field, and many helpful conclusions may be deduced from a study of the facts thus obtained. A comparison of the conditions met with in a given territory with those in other better known fields may also be of great assistance, but for furnishing specific information regarding the occurrence of the oil in any particular area there is just one instrument, and that is the drill.

From the drilling of wells in the Coalinga field during the last ten years a large body of useful data concerning the underground conditions has been accumulated, and whatever accuracy and value there is in the underground map and in the statements concerning the geology of the wells in this report is due almost entirely to the generosity of the operators in this field in supplying the information. The writers therefore wish to acknowledge their indebtedness to the officers, managers, and other operators of the different oil companies for their hearty cooperation and support. Thanks are due more particularly to Messrs. Jas. H. Pierce, W. W. Orcutt, S. A. Guiberson, jr., R. W. Dallas, A. and H. Kreyenhagen, A. M. Anderson, H. G. Anderson, J. M. Atwell, Charles Babtie, Gordon M. Baker, R. C. Baker, Balfour Guthrie & Co., Orlando Barton, H. J. Bender, Scott Blair, S. R. Bowen, F. S. Brack, H. H. Brix, C. A. Canfield, Frank Cleary, H. R. Crozier, F. P. Dagany, P. B. Daubenspeck, D. M. De Long, J. F. Ecbert, Andrew Ferguson, A. D. Ferguson, W. S. Fisher, A. D. Fram, Charles Fredeman, W. M. Graham, W. A. Gray, W. A. Greer, L. P. Guiberson, H. D. Guthrey, S. H. Hain, H. H. Hart, H. Henshaw, W. A. Hersey, Paul Huntsch, W. A. Irwin, W. H. Kerr, W. P. Kerr, J. E. Kibele, Besley Lafever, J. L. Lennon, M. E. Lombardi, E. W. Mason, W. G. McCutcheon, W. O. Miles, J. H. Miller, S. E. Mills, R. B. Moran, T. A. O'Donnell, P. F. Page, R. S. Peeler, Z. L. Phelps, J. H. Raney, Charles V. Reynolds, George D. Roberts, C. N. Root, Guy H. Salisbury, George Schwinn, Max Shaffrath, R. E. Shore, R. H. Smith, H. F. Stranahan, R. E. Thompson, T. H. Turner, J. Waley, J. L. D. Walp, Alex Wark, J. H. Webb, M. L. Woy, J. B. Wrenn, John M. Wright, and many others who have contributed in one way or another to the value of the report.

The writers also wish to express their gratitude to R. B. Marshall, geographer in charge, and to E. P. Davis, topographer, for favors rendered during the course of the field season, when the topographic and geologic work were going on simultaneously.

Advantage of cooperation among operators.—The outlook will continue to be bright for the development at Coalinga of one of the greatest fields in California if each and every operator will conserve to the utmost the wonderful supply of oil stored within the boundaries of the district, and by wise management aid in keeping it available. The amount of available oil in the territory covered by the underground-contour map (Pl. II, in pocket) is estimated at 2,825,000,000 barrels. Contrary to the belief of some people, the underground resources of the earth are not inexhaustible; when the oil in any field is once gone it will not be replaced for many centuries, if ever. It may be true that the processes of oil formation and migration are constantly taking place in some localities, but such processes are so exceedingly slow, if measured in years, that for practical purposes they may be considered as having ceased altogether.

Fortunately the Coalinga field has had little of the serious trouble with water that is ruining certain parts of some of the other fields of California. This lack of trouble is probably due largely to the little disturbed condition and uniformity of the oil formations over most of the territory. But trouble from water is beginning to show its effects in certain parts of the field, and, through accident or carelessness, some wells not yet abandoned are believed to be letting water into sands that are productive in not far-distant wells. In order to avoid the dangers incident to faulty drilling and handling of wells, the operators should meet and exchange information about the underground geology. It seems shortsighted for one operator to withhold from his neighbor his logs and other information about underground conditions, when this very withholding may be the cause of his neighbor's flooding a large area through lack of proper knowledge in shutting off the water. Furthermore, it is hoped that those in legislative authority will recognize the needs of the petroleum interests in California, and, as has been done in other States, provide laws protecting the producers from negligent, shortsighted, or criminally careless operators.

GEOGRAPHY AND TOPOGRAPHY.

LOCATION.

The region mapped and referred to in this report as the Coalinga district is situated in the southern part of Fresno County and the western part of Kings County, Cal., and is bounded on the south by the Kern County line. It forms a long strip of territory extending from 119° 50′ west longitude and 35° 47′ north latitude at its southeast corner to 120° 37′ west longitude and 36° 20′ north latitude at its northwest corner, along the foot of the Diablo Range. This is the easternmost member of the Coast ranges on the border of the San Joaquin Valley of California. The district as mapped is roughly 50 miles long and 15 miles wide and includes about 700 square miles. It covers the foothill belt along the valley and extends back into the high hills to the summits of the first surrounding mountain ridges, its northwest and southwest corners reaching to the crest of the Diablo Range.

The developed oil territory commonly referred to as the Coalinga field is in the northern part of the district, in the foothill region around Pleasant Valley, where the town of Coalinga is situated. This is the only important settlement in the district or in a large surrounding region, the country being very sparsely inhabited. A railroad line connects Coalinga with the main lines of the Southern Pacific and the Atchison, Topeka and Santa Fe railroads in the San Joaquin Valley, and wagon roads enter the district at several points from the valley on the east. Roads cross the Diablo Range from the west by four routes, (1) over the Benito Pass at the head of Los Gatos Creek, (2) over the divide between Priest Valley and the head of Waltham Creek, (3) across the range between Stone Canyon and Waltham Creek, and (4) over Cottonwood Pass. The first enters the Coalinga district along Los Gatos Creek, the second and third along Waltham Creek, and the fourth through McLure Valley.

DEFINITIONS OF PLACE NAMES.

It is important that the names of the various places and features in the Coalinga district used in this report should be clearly defined before the topographic and geologic discussion is begun. The region is one in which little detailed investigation has been made, and most of the natural features are unnamed, while to many others names are indefinitely applied. The following definitions of names that have been newly applied and of names whose application has been made more definite have been submitted to the United States Geographic Board and have been approved and made permanent by that body. Most of these names appear on the map (Pl. I).

Coalinga district.—The application of this name to the whole region included in the map has been discussed in the preceding paragraphs.

Coalinga field.—The term field has been adopted as representing a subdivision of a district, and the name Coalinga field is used in this report in its accepted sense as meaning the region of the developed oil field in the northern portion of the territory mapped, round about the valley (Pleasant Valley) in which Coalinga is situated. This region is in turn subdivided into the Eastside, Westside, and Oil City fields, which are well known and will be defined later (pp. 74–107).

Kreyenhagen field.—Similarly the region of the hills west of Kettleman Plain is referred to as the Kreyenhagen field.

Kettleman Hills field.—The possible future oil field east of the Kettleman Plain will be referred to as the Kettleman Hills field.

Diablo Range.—The southern limit of the Diablo Range has been fixed at Antelope Valley in northwestern Kern County. Heretofore the name has been used indefinitely for part or all of the easternmost members of the Coast Range extending southeastward from the Carquinez Straits. Antelope Valley is fixed as the southern limit of the range because the mountains there sink into low spurs, and the continuation of the mountain belt beyond is a markedly individual range that is en échelon with Avenal Ridge, between Antelope and McLure valleys, which is the southernmost spur of the Diablo Range. The United States Geographic Board has determined that the correct name is Diablo Range, instead of Mount Diablo, Monte Diablo, or Sierra del Monte Diablo.

Temblor Range.—Southeast of Antelope Valley a range of distinct topographic and structural individuality forms the divide between the San Joaquin Valley on the northeast and the basin of San Juan Creek and the Carrizo Plain on the southwest. It extends from Cholame Creek on the north to about latitude 35°, where it merges with the high mountain mass around Mount Pinos called the Tejon Mountains. To this range the name Temblor is here applied. This name, which is Spanish for earthquake, is particularly suited to the range for two reasons. First, because the great California fault line, along which earthquakes have repeatedly originated, follows the range from one end to the other, being in the very heart of it throughout its northern part. A pronounced scarp resulting from the movement in 1868 can still be traced for much of the distance along this line. Second, because the well-known old Temblor ranch, west of McKittrick, is situated on its flanks.

Joaquin Ridge.—A very prominent structural ridge, here named Joaquin Ridge, runs east-southeast from the high mountains south of San Carlos Peak to the San Joaquin Valley north of Coalinga, forming the divide between Los Gatos Creek on the south and tributaries of Salt Creek and Cantua Creek that run northeastward to the San Joaquin Valley. The ridge heads at a mountain almost 5,000 feet high, situated in the southeastern portion of T. 18 S., R. 12 E., in the northeast corner of the area mapped, on the divide between the tributaries of Los Gatos Creek and San Benito River. Its summit is serrated with picturesque rocks, one striking group of which is locally known as the Joaquin Rocks. The oil field north of Coalinga lies on the nose of this ridge.

Anticline Ridge.—Southeast of a depression in the Joaquin Ridge in the southern part of sec. 34, T. 19 S., R. 15 E., a low broad line of hills extends about 6 miles to the railroad line in the gap formed by Los Gatos Creek. This ridge is formed by a perfect anticlinal nose and is therefore referred to as Anticline Ridge.

Juniper Ridge.—A corresponding and approximately parallel ridge runs south of Los Gatos Creek from the divide between that stream and Lewis Creek as far as the canyon of Waltham Creek (Alcalde Canyon). It is a high, rugged ridge separating the important Waltham Valley depression on the southwest from the Los Gatos Creek depression on the northeast and from the low hills between Los Gatos and Waltham creeks (Alcalde Hills) on the east. It is cut abruptly by Waltham Creek, south of which it is continued for about 2 miles in the isolated ridge known as Curry Mountain. It is here called Juniper Ridge owing to its characteristic vegetation.

Avenal Ridge.—The name Avenal Ridge is here applied to the mountains separating Avenal Creek and McLure Valley from the Cholame and Antelope valleys. It is the southernmost of the spurs of the Diablo Range. The name, which means a field of oats, is appropriate because the hills forming the ridge are rounded and grass grown.

Reef Ridge.—A prominent escarpment faces the low hills that border the Kettleman Plain, running southeastward from the southern fork of Jacalitos Creek (Jasper Canyon) as far as Little Tar Canyon, north of Dudley. This is formed by the prominent lower Miocene fossiliferous strata termed the "Reef beds," which dip at a high angle and, owing to their resistance to erosion, rise high above the softer sand hills on the northeast. This escarpment forms the northeastern flank of a ridge to which the name Reef Ridge is here applied. The name is expressive of its prominent topographic character.

Alcalde Hills.—The foothills between Los Gatos and Waltham creeks, east of Juniper Ridge, northwest of Alcalde and west of Coalinga are here called the Alcalde Hills.

Jacalitos Hills.—The foothills between Waltham and Jacalitos creeks are here called the Jacalitos Hills. Xacalli is an Aztec word adopted by the Mexicans, meaning Indian hut or wigwam, and Jacalitos means the little wigwams.

Kreyenhagen Hills.—The foothills southeast of Jacalitos Creek between Reef Ridge and Kettleman Plain may be named Kreyenhagen Hills. The name is that of three families owning large tracts of land there. They are early settlers and practically the only inhabitants, and the region is generally known as the Kreyenhagen country or Kreyenhagen's. Kreyenhagen field is the name used in this report for the oil field of the vicinity.

Pyramid Hills.—A long narrow line of hills borders the eastern side of McLure Valley, extending from Little Tar Canyon about 3 miles north of Dudley to the gap (Dagany Gap) where the Avenal flows out of the valley about 4 miles south of Dudley; south of this gap they continue into the Devils Den region. They form a ridge capped by a succession of conical hills, which when viewed from the east appear like isolated pyramids, and are therefore here called the Pyramid Hills.

Tent Hills.—A somewhat similar line of hills of peculiar topographic and geologic structure extends along the Avenal at the northeastern foot of the high ridge (Avenal Ridge) west of McLure Valley. They begin about 4 miles west of Dudley and run 3½ miles northwest, being separated from Avenal Ridge by a marked depression. Owing to the resemblance of the individual hills to tents they are here called the Tent Hills.

Guijarral Hills.—Immediately southeast of Anticline Ridge, on the opposite side of the railroad, is a small low group of gravelly hills referred to in the text as the Guijarral Hills. The word is Spanish and means a heap of pebbles or a place abounding in pebbles.

Dagany Gap.—The name Dagany Gap is used for the gap at the lower end of the McLure Valley south of Dudley. It is named from an old settler of that region.

Avenal Gap.—The Kettleman Hills are cut at latitude 35° 50′ by a completely graded stream channel now followed by Avenal Creek. It will be referred to as Avenal Gap.

Polvadero Gap.—At their northern end the Kettleman Hills are separated from the Guijarral Hills by a gap through which flow Zapato and Canoas creeks. It is called Polvadero Gap because it is subject to dust storms. Certain of the early land maps have it Pulvero, but this is not correct.

Pleasant Valley.—At least a portion of the valley at the mouth of Los Gatos Creek has been known as Pleasant Valley, the usage not being definite. The name may well be applied to the whole basin in which Coalinga is situated.

Waltham Valley and Creek and Alcalde Canyon.—The creek at the mouth of which Alcalde is situated is variously known as Wartham, Warthan, Waltham, and Alcalde. The United States Geographic Board has decided that Waltham is the correct name. This stream heads in a broad structural valley having no relationship in geologic character with the canyon through which it flows lower down. The name Waltham Valley, already in use for this upper valley, should be restricted definitely to it and not applied to the lower canyon, which it seems advisable to distinguish under the name Alcalde Canyon, thus preserving a name which is already understood as referring only to the lower part. This name is therefore applied to the canyon extending from the edge of Waltham Valley, where the stream cuts between Juniper Ridge and Curry Mountain, to Pleasant Valley. The stream itself bears the same name throughout.

McLure Valley.—The valley in which Dudley is situated has long been known as McLure Valley, after an early settler, now dead. According to old inhabitants this is the original and proper name. It is widely known also as Sunflower Valley, by reason of the abundant growth within it of wild sunflowers. The United States Geographic Board has decided that the former is the correct name.

Kettleman Hills and Plain.—The United States Geographic Board has decided that the name applied to these features should be written with an "e" and should not be spelled Kittleman.

Various creeks and canyons.—The United States Geographic Board has considered the various usages in regard to the names of the creeks in the Coalinga district, and the results of its decisions appear on the map (Pl. I, in pocket).

For convenience of reference the authors have applied names to several canyons in the district. The one which runs north and south 7 to 10 miles due north of Coalinga, and which is followed by the road to Oil City, is named Oil Canyon. The one in the Alcalde Hills which runs southeastward across sections 2, 11, 12, and 13, T. 21 S., R. 14 E., and which throughout its course across sections 2, 11, and 12 is practically coincident with an anticline, is called Anticline Canyon.

The application of the name Alcalde Canyon has been shown above. The southern fork of Jacalitos Creek may be appropriately named Jasper Creek from the picturesque and brilliant colored buttes of jasper that surround its upper portion, and the name Jasper Canyon is therefore applied to the gorge cut by this stream across the northwest end of Reef Ridge. The sharp canyon cut through Reef Ridge by Zapato Creek is called Zapato Canyon, and the similar one formed through Reef Ridge by the southern fork of Zapato Creek 2 miles farther east may be named Sulphur Spring Canyon, from the abundance of sulphur water that issues in it. The similar canyon at the head of Canoas Creek is called Canoas Canyon. The names Big Tar Canyon and Little Tar Canyon are in common use for the features to which these names are applied on the map.

Laval grade.—The Laval grade is a name locally known for the road leading northeastward up a branch of Oil Canyon, starting in that canyon on the eastern side of the NW. ¼ sec. 29, and crossing the ridge at the head of this branch canyon in the center of the NW. ¼ sec. 21, T. 19 S., R. 15 E.

GENERAL TOPOGRAPHIC FEATURES.

The Coalinga district owes its broader topographic features to its position along the border between the Coast Range and the San Joaquin Valley. It is largely a region of foothills that rise on the west into the mountains and merge on the east with the wide level plain. The foothills form several groups around the base of spurs descending southeastward from the Diablo Range, the groups being separated from each other by reentrant valleys that open out to the San Joaquin Valley.

The Diablo Range in this latitude is a rugged mountain group made up of various component members, some of which, owing to a complication of structures, run at angles oblique to the main trend of the range northwest and southeast. The crest of the range has a general altitude varying between 2,500 and 5,000 feet, and declines in height from the region northwest of the Coalinga district toward the region southwest of it, where it has been assumed as coming to a stop and giving place on the southwest to the Temblor Range. Portions of the watershed appear upon the map (Pl. I) at only two points, viz, in the northwest corner, which is marked by a peak nearly 5,000 feet high that stands at the head of Joaquin Ridge; and in the southwest corner, where the much lower Avenal Ridge, the southernmost spur of the range, appears. In the intermediate region the ridges that are represented on the edge of the map are in general separated from the main divide of the range by a region of lower relief determined by the presence of transverse structural valleys, of which Waltham Valley is the principal example. The general topographic development is youthful, but there is evidence in certain localities of different stages of development up to advanced youth. A feature of the relief of the whole region is the topographic reflection of the geologic structure, a feature that is especially pronounced in the foothills belt, with which this report particularly deals.

A peculiar feature of the Diablo Range is the occurrence along its eastern flanks of many spurs running out toward the southeast, and of reentrant valleys between these spurs. These ridges and valleys have an orientation slightly more to the east and west than that of the whole range, which trends in general about N. 36° to 40° W. and S. 35° to 40° E. They are primarily due to structural causes and not to erosion. The main salients of the Diablo Range that project toward the San Joaquin Valley in the Coalinga district are Joaquin Ridge and the Kettleman Hills, Juniper Ridge and Curry Mountain, Reef Ridge, the high hills northwest of McLure Valley between the drainage of Big Tar Canyon and Avenal Creek, and Avenal Ridge. These and the valleys or depressions separating them are the topographic expression of structural features running transverse to the main trend of the Diablo Range and are en échelon with each other.

Joaquin Ridge is anticlinal and exposes on its lower flanks the oil-bearing formations, thus determining the position of the oil field north of Coalinga. The ridge is structurally continued by the Kettleman Hills, which form a prominent isolated group rising over 1,000 feet above the San Joaquin Valley. The spur formed by Joaquin Ridge and the Kettleman Hills is separated from the rest of the district by the synclinal and faulted depression of White and Los Gatos creeks and the synclinal Pleasant Valley and Kettleman Plain. The two latter form a continuous, almost level, graded plain, opening only locally into the San Joaquin Valley through narrow gaps formed by graded stream channels.

Juniper Ridge and Curry Mountain, southeast of the Los Gatos Creek and Pleasant Valley depression, form a continuous structural feature probably due to faulting on the southwest side. In the southeastern portion of this spur it presents a steep scarp on the southwest bounding Waltham Valley, and on the northeast a gradual monoclinal slope into the Alcalde Hills. The end of Curry Mountain drops abruptly into a depressed area of low rolling hills (the Jacalitos Hills) that is the continuation southeastward of the Waltham Valley depression. Beyond this area a prominent salient springs up along Jacalitos Creek and extends southeastward as a high divide between the belt of lower relief, in which Jacalitos, Zapato, Canoas, and Big Tar creeks head, and the foothills bordering the Kettleman Plain. This divide is Reef Ridge, and all the streams named, as well as their forks, cut deep gorges through it. The ridge has a general monoclinal structure, the component strata dipping steeply northeastward into the foothills. The ridge is due, in large part at least, to the resistant qualities of the Vaqueros and Tejon strata forming its crest. At its southeastern extremity it gives place to the minor ridge of the Pyramid Hills, which is en échelon with it.

The next important salient enters the area shown on the map at a point south of the head of Big Tar Canyon and the Castle Mountain fault zone. It is a high and prominent group of hills forming the eastward continuation and the end of the precipitous ridge of Castle Mountain. Reef Ridge and the last-mentioned hills are separated from the next salient to the south by the wide plain of McLure Valley and by the valley of Avenal Creek. This depression is comparable in structure and size with Pleasant Valley. Southwest of McLure Valley rises Avenal Ridge, the main divide of the Diablo Range. It is formed by an important closely folded anticline that plunges steeply southeastward and brings the range to an end. Still farther southwest, on the opposite flank of Avenal Ridge, extends the large Antelope Valley, which is of the same peculiar structural type as the valleys already mentioned.

The foothills that swing around the bases of these spurs of the Diablo Range form a rolling surface that descends gradually to the surrounding plains. They owe their form chiefly to three causes: (1) The general reflection, on the surface, of the folds to which their uplift is due; (2) erosion along lines directed down the slope toward the valleys, at right angles to the structural lines, as a result of which a series of lateral ridges is formed; and (3) erosion along structural lines, particularly along bedding planes and lines of contact, as a result of which parallel longitudinal ridges and valleys and rows of hills are formed, and the lateral ridges deformed or dissected into hills. The succession of longitudinal ridges and intervening symmetrical troughs, to which the name Canoas, meaning canoes, probably refers, is a particularly striking feature of the Jacalitos and Kreyenhagen hills. Further detailed sculpturing is due to erosional wash along small channels tributary and at right angles or oblique to the streams determined by these two main factors. The soft formations of which the hills are largely composed lend themselves to minute, rapid, and fairly uniform sculpturing, which gives the hills a wrinkled appearance, especially evident when the rays of the sun, falling obliquely, cause an intricate scattering of light and shade. A general similarity of elevations is characteristic of the foothill areas, which, as a rule, show comparatively slight relative relief.

The two most important streams of the district are Los Gatos and Waltham creeks, which drain considerable areas and flow through deep, structurally important, and, in their lower portion, nearly graded valleys. These streams join in Pleasant Valley and pass out to the San Joaquin Plain through a gap cut across the uplift of the Coalinga anticline. The deep sharp canyon cut by Waltham Creek through Juniper Ridge and Curry Mountain and thence eastward for over 3 miles to Alcalde is worthy of remark. Other important streams are Jacalitos, Zapato, and Avenal creeks, of which much the same can be said, except that the origin of the lower courses of the former two is not so much due to structure as is that of the others mentioned. All of these are antecedent to the latest structural movements and form sharp cuts across features that have been uplifted in their path during Quaternary time. Owing to the slight rainfall in this region and the prolonged drought in summer none of these streams carries much water, and they all become nearly dry during the dry season.

Tulare Lake borders the southeastern portion of the Coalinga district east of the Kettleman Hills. It is broad and shallow, occupying a portion of the almost level floor of the San Joaquin Valley. It is supplied with water by several rivers descending the Sierra Nevada and has no outlet. Owing to unusual precipitation during 1907 it extended its borders widely, reaching nearly to the base of the Kettleman Hills. During preceding years the lake had been drying up and had almost ceased to exist. Its border as shown on Pl. I, therefore, represents an abnormally extended position.

GEOLOGY.

GENERAL STATEMENT.

The eastern slope of the mountains bordering the San Joaquin Valley is formed by a great thickness of strata dipping toward the valley. The oldest rocks exposed appear in the axis of the mountain range at the base of the monocline, successively younger formations appearing eastward as the edge of the valley is approached. The different formations that may be recognized as units in this series, with the time divisions to which they correspond, are as follows, from the oldest to the youngest: Franciscan (Jurassic?), Knoxville (lower Cretaceous), Chico (upper Cretaceous), Tejon (Eocene), Vaqueros (lower Miocene), Santa Margarita (upper middle Miocene), Jacalitos (early upper Miocene), Etchegoin (uppermost Miocene), Paso Robles (Pliocene and early Pleistocene), and late Quaternary alluvium and terrace deposits. These formations, with the exception of certain igneous and metamorphic rocks associated with the Franciscan, are of sedimentary origin, the sediments being marine, with the exception of most of the Paso Robles and later deposits. They indicate that the greater portion of the area included within the Coalinga district was beneath the sea during intervals occupying probably the major portion of the time from the Jurassic to the end of the Miocene. The latest movements of the land, which produced the features of topographic relief now to be seen, did not take place until within Quaternary time.

The first three of the above formations are of little importance in this district in connection with the occurrence of petroleum. The Tejon and Vaqueros are the principal reservoirs of the oil, and are therefore of prime importance. The Santa Margarita and Jacalitos are petroliferous only at their bases, and their upper beds, together with those of the Etchegoin, are the strata which overlie the oil sands and through which the wells are drilled, so that their relation, thickness, character, and structure have an important bearing on the problem of accessibility of the oil and are worthy of detailed study. The Paso Robles formation is of less direct importance in this connection, but is of aid in throwing light on the structure and the relations of the different formations.

STRATIGRAPHY.

FRANCISCAN FORMATION (JURASSIC?).

General description.—The central portion of the Diablo Range is occupied by an old and for the most part much-altered formation that is in every way similar to the well-known Franciscan formation of other parts of the State. It comprises the oldest rocks here exposed, as it antedates the Knoxville (Lower Cretaceous), but further than this little can be said regarding its age. It is usually considered Jurassic, but elsewhere there is no good fossil evidence of its age, and in this region none has been found.

The Franciscan is easily recognizable, as it is characterized by typical rocks and topography. The most characteristic feature of the areas occupied by the Franciscan is the serpentine, which is everywhere associated with it and which is here considered a part of it, although in reality intrusive in the sedimentary rocks, and therefore of later age. The original sedimentary rocks, which are sandstone, shale, and jasper, occur in detached areas and are greatly disturbed. They are intimately associated with glaucophane, actinolite, and other schists; serpentine, and other metamorphic rocks; and in one area shown on the map with soda-bearing hornblende syenite. In the portion of the Coast Range within and bordering the Coalinga district the metamorphic rocks of the Franciscan formation greatly predominate over the unaltered ones. In the small area of Franciscan sedimentary beds in the northwest corner of the district, the alternating beds of sandstone and shale closely resemble the strata in the lower portion of the Knoxville-Chico and are difficult to separate from them. The serpentine covers a much larger area and extends far beyond the limits shown on the map over a continuous stretch estimated as being at least 40 square miles. The Franciscan formation and associated rocks are considerably mineralized and contain deposits of cinnabar, asbestos, and the newly described gem mineral, benitoite.[a]

Importance with relation to petroleum.—The rocks of the Franciscan are not known to contain any petroleum. The formation is of different character from the formations in which the oil is found and has no direct relation to them. Even if it had once been a source of petroleum, the disturbance that it has undergone could have allowed little to remain.

KNOXVILLE-CHICO ROCKS (CRETACEOUS).

General description.—The next oldest rocks exposed in the Coalinga district comprise a thick series of strata of sandstone, shale, and conglomerate overlying with probable unconformity the Franciscan formation just described, and covering a wide belt for the most part west of the foothill region. They form the high hills north and south of Los Gatos and Waltham creeks and may be easily recognized by the dark, thin-bedded, compact shale and sandstone of the lower portion and the massive, drab, concretionary sandstone of the upper portion. These rocks are of Cretaceous age and comprise part or all of the two formations well known elsewhere on the west coast as Knoxville (lower Cretaceous) and Chico (upper Cretaceous). Owing to the lack of fossil or stratigraphic evidence in the Coalinga district sufficient to form the basis for a separation between these two formations, they are mapped and described together for the present.

The rocks, however, may be separated lithologically into three divisions. A marked distinction between the lower and upper portions has already been noted, but the thin-bedded shale and sandstone making up the lower portion is divided into two parts by a

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[a] Louderback, G. D., Benitoite, a new California gem mineral, with chemical analyses by W. C. Blasdale: Bull. Dept. Geol. Univ. California, vol. 5, No. 9, July, 1907. pp. 149-153. Also, Arnold, Ralph, Notes on the occurrence of the recently described gem mineral benitoite: Science, new ser., vol. 27, No. 686, February 21, 1908, pp. 312-314.

conformably interbedded zone of coarser sediments and in places by several hundred feet of coarse massive conglomerate, as along Alcalde Canyon and on Juniper Ridge.

The beds above and below the conglomerate zone are of the same character, predominantly dark argillaceous shale in thin layers with partings of sandstone, but it is possible that the conglomerate zone represents an important stratigraphic separation. Chico (upper Cretaceous) fossils have been found north of White Creek and near Alcalde in the shale series at horizons higher than the conglomerate, and it is possible that the zone of coarsening in the sediments represents the base of the Chico. The beds below the conglomerate are at least 3,000 feet thick, and probably belong to the Knoxville (lower Cretaceous). Fossils of this age have been found in similar beds in the Devils Den region, not far south of the area mapped. The strata of the middle division, above the base of the conglomerate, have a thickness of at least 4,800 feet.

The uppermost of the three divisions is predominantly sandstone, and has a thickness of at least 3,500 feet. The sandstone is usually of a drab color, medium grained, and not very hard. It occurs in massive beds, often weathering cavernous, that stand out prominently and display the structure on the sides and tops of the ridges north of Los Gatos Creek and west of Coalinga. Rocks of this division may be easily recognized by these characteristic outcrops and by the numerous large, hard, reddish-brown concretions of which the sandstone is full and which weather out and remain in patches on the surface. The beds are in places so concretionary that the individual oval concretions lose their identity and the beds are composed throughout of hard brown rock like that forming the concretions. The prominent sandstone strata are separated by poorly exposed, softer beds of sand and light-colored shale. Locally the sandstone is conglomeratic. Thin seams of calcareous shale and sand are at some points interbedded with the softer beds. At the base of this division of the Knoxville-Chico rocks, the massive sandstone beds give place to thinner beds alternating with finer-grained sandstone and shale, and these grade over into the thin-bedded series described as the middle division. The transition takes place within a few hundred feet, and in places a fairly sharp line can be traced between the beds that are predominantly sandstone and those in which the thin layers of fine grain predominate. Fossils of Chico (upper Cretaceous) age occur at various localities in sandstone and conglomerate in the lower portion of this upper division; the upper portion has not furnished fossils and can be only doubtfully referred to the Chico formation. The upper part of the concretionary sandstone series may be either Chico or Tejon (Eocene), or a transition between these two formations. The division is, however, fairly homogeneous in character and seems to represent a separate stratigraphic unit, and it is therefore, for the time being at least, referred as a whole to the Chico formation; considered as such, it is strikingly distinct from the divisions below and from other formations in the district.

Importance with relation to petroleum.—The Knoxville-Chico strata are not petroleum bearing so far as known. It is possible that traces of oil may be found in them, but there is nothing to indicate that they contain it in quantity sufficient to be of economic importance. The beds underlie the Tejon (Eocene) formation, in which the petroleum of the Coalinga district is supposed to have originated, and below which no petroleum has been found.

TEJON FORMATION (EOCENE).

General description.—The beds of the Knoxville-Chico are overlain unconformably by beds belonging to the Tejon (Eocene) formation. This is a marine sedimentary formation, which was named from the locality near Fort Tejon in Kern County, where it occurs typically. It forms a belt along the western edge of the San Joaquin Valley and is exposed intermittently in the region between the type locality and the Coalinga district. No sharp line of demarcation is to be drawn between the Tejon and the underlying Chico in the northern part of the district, and in places there appears to be a gradation from the beds of the former into those of the latter, as if they had been formed during a continuous period of sedimentation.

The Tejon formation in the Coalinga district is made up entirely of sedimentary strata that dip toward the San Joaquin Valley in the monocline along the eastern flank of the mountains, and are exposed on the surface in a narrow discontinuous belt between the beds of Cretaceous which underlie them and those of the Miocene which overlie them. Broadly speaking, the Tejon formation here may be divided into a lower sandstone portion and an upper shale portion, but no sharp division can be made that will be applicable throughout the district under discussion. The most important and distinctive feature of the formation is the predominantly fine-grained nature of the beds toward the top as compared with those below. The Tejon comprises a thickness of from 1,400 to 2,300 feet where exposed most completely, the upper half of which is made up of thin beds of whitish and purplish, siliceous, argillaceous, and locally calcareous shale which is easily recognizable and which lends individuality to the formation. The lowermost few hundred feet are of variable sandy beds locally fossiliferous. The upper shale is very similar—especially in some places, as north of Coalinga—to the siliceous shale of the formation along Reef Ridge described later as the Santa Margarita, and the two must not be confused. Where the

Tejon formation is thick, the shale portion forms a greater proportion of the whole than does the sandstone, the middle beds being chiefly of fine grain. The middle beds differ from those at the top in being more argillaceous, of a darker color, less prominent, and more frequently interbedded with sandy beds.

There are three separate areas in which the Tejon is exposed, one in the oil field north of Pleasant Valley, another on the eastern border of the Alcalde Hills just west of Coalinga, and the third along Reef Ridge. Between the Alcalde Hills and Reef Ridge it is covered, as is the Cretaceous below, by the overlapping Miocene beds.

North of Pleasant Valley.—In the northern region the Tejon is typically exposed in the hills directly north of Coalinga in the vicinity of the camp called Oil City. Here it seems to be conformable with the Chico and to represent either continuous sedimentation between the Cretaceous and Eocene or else a period of tranquil conditions between the deposition of the two formations. The line of contact between them shown on the map represents the top of the hard, brown, concretionary beds, which are assumed to be the uppermost Cretaceous beds of this district. The Tejon (Eocene) beds are markedly unconformable with those of Miocene age above, which lie with a low dip upon the sharply folded and overturned shales characteristic of the upper part of the Tejon. The formation is here more completely exposed than elsewhere within the district and has a thickness of at least 2,300 feet. The uppermost beds for a few hundred feet down are chiefly of white, siliceous, hard and brittle, thinly bedded diatomaceous and foraminiferal shale. This shale grades below into softer, crumbly, very gypsiferous, thinly bedded clay shale and sandy shale of a purplish-brown color, which makes up the greater part of the formation. The shale is locally variable in color, assuming different yellowish and reddish tints as the result of staining by petroleum. It contains an abundance of crystallized gypsum with minor amounts of alkaline mineral matter and sulphur along the intricate fracture planes. Numerous dikes of sandstone traverse the beds in various directions, and sand and sandstone of variable character are interbedded in lesser amounts with the shale in the middle of the formation. The lowermost 700 to 1,000 feet is made up chiefly of interbedded hard and soft sandstone that is variable in color, but is frequently yellowish. The bedding throughout the formation is usually thin and inconspicuous, and especially in the upper half is apt to be very irregular.

Southwest of Oil City the Miocene beds gradually lap more and more upon the Eocene, leaving less of it exposed. Owing to lack of exposures of the underlying rocks for 1 or 2 miles north of Los Gatos Creek, where it opens out to Pleasant Valley, and the structural complexity of that area, the lines of contact drawn there are theoretical and are at best only approximately correct.

South of Los Gatos Creek.—The outcrops of Tejon appear again south of Los Gatos Creek, in a belt along the base of the foothills facing Pleasant Valley. The formation is conformable with the Chico and the rocks near the contact are fairly well exposed. The line drawn at the top of the concretionary beds, which are supposed to be at the top of the Chico (upper Cretaceous), marks the base of some beds of light-yellow and white, soft, gypsiferous sand that are taken as the lowermost Tejon (Eocene) of this district. Within 100 feet above this contact occurs a bed of a calcareous sandstone locally greatly hardened and full of typical Tejon fossils. At the two coal mines northwest of Coalinga the yellow sand at the base of the formation is exceedingly gypsiferous and variable in character, and appears to be a shallow-water deposit. It contains seams of lignite and carbonized wood, which in former years have been mined. Above this sand, which has a thickness of about 200 feet, occur thin beds of light-colored, somewhat siliceous, hard shale, and soft, purplish-brown, gypsum-bearing argillaceous shale, composing the upper half of the formation. The latter beds are steeply tilted and fractured, and their truncated edges are overlain by Miocene beds with low dip. The unconformity is well exposed in the canyon of the San Joaquin Valley coal mine. At one place 4 miles northwest of Coalinga, within 500 to 600 feet above the base of the Tejon, there is exposed a bed of soft diatomaceous shale which probably represents part of the siliceous zone toward the top of the formation farther north, although it is not impossible that it occurs within the Miocene beds. Owing to the covering of soil on the undulating ground at the edge of the plain northwest of Coalinga the thickness and extent of this diatomaceous material, or of the formation as a whole, can not be determined. It may be said, however, that the shale portion of the formation has a thickness in this part of the field of at least 300 feet below the highest horizon that the unconformably overlying Miocene leaves exposed. The Miocene spreads more widely over the Tejon farther to the south until the strike of the latter carries it completely beneath the Miocene beds at a point about 3 miles west of Coalinga.

Reef Ridge.—Beds of Tejon age appear again on Reef Ridge, where the same broad lithologic characteristics may be noted, namely, a sandy, frequently yellowish lower portion, and a purplish shaly upper portion, although many minor differences are evident in the manner of occurrence north and south of the Miocene overlap. The Tejon beds of Reef Ridge, as compared with those in the northern locality, are in general more indurated and more regularly and steeply tilted. The sandstone is more massively and regularly bedded and coarser at the base, and the shale is of different character and more homogeneous. The formation rests on what is with little doubt a lower portion of the Cretaceous, probably unconformably. An angular unconformity between the Tejon and the Miocene beds above it on Reef Ridge was not plainly found as it was in the Coalinga field, but there is good reason to believe that an unconformable relation exists between the two formations here as well as farther north.

The Tejon of Reef Ridge is exposed typically in the gorges that cut this ridge between Zapato Canyon and Big Tar Canyon. It is made up of a basal zone of conglomerate ranging in thickness from a few feet to over 100 feet, of a succession of sandstone beds aggregating about 550 feet in thickness, and of an upper shale portion of which a thickness as high as 900 to 1,000 feet is in places exposed. The Tejon becomes thinner west of Zapato Canyon and is not known to outcrop in that direction west of Jasper Canyon. Toward the southeast the Tejon passes under the overlapping Santa Margarita (upper Miocene) near the extremity of Reef Ridge and disappears entirely. Only one small outcrop of it was found on the southwest side of McLure Valley. It was probably deposited over much of this region and later removed by erosion before the deposition of the Santa Margarita formation, which rests directly upon the Cretaceous beds. Rocks of Eocene age reappear still farther south in the Devils Den region and beyond.

The sandstone of the Tejon formation may be easily recognized by the prominent line of peaks that it forms along Reef Ridge a few hundred feet behind the abrupt frontal escarpment produced by the "Reef beds." It is for the most part homogeneous, yellowish-gray, medium-grained, oil-stained, massive sandstone, locally very hard, especially in the upper portion, but usually fairly soft. In places it is concretionary and becomes cavernous by weathering. A characteristic feature of it is that it supports a heavy growth of vegetation as compared with the shale above it. It attains its greatest development in the central portion of its extent and thins toward the two ends of Reef Ridge.

This sandstone contains typical Tejon (Eocene) invertebrate fossils which place it definitely in this formation and allow its correlation with the fossiliferous sandstone of the Tejon, already described from the Coalinga field. At its base it grades into the locally variable conglomerate zone before mentioned, which is taken as marking the base of the formation for the reason that it rests unconformably upon the dark Cretaceous shale in the region of Big Tar Canyon and the head of Garza Creek. Farther west, however, in the vicinity of Canoas and Sulphur Spring canyons, the coarse beds at this horizon rest with apparent conformity and intergradation upon a great thickness of beds of sandstone and soft sandy shale and carbonaceous clay shale that are unlike Cretaceous strata of other parts of the district. It is possible that this underlying terrane is part of the Tejon formation that is lacking elsewhere, but it is mapped for the present with the Knoxville-Chico (Cretaceous). No fossils have been found in it and sufficient work has not been done upon it to determine its relations.

The shale overlying the sandstone of the Tejon is less resistant to weathering and forms a belt of low topographic relief between the line of peaks formed by the lower sandstone and the sharp ridge of the Vaqueros (lower Miocene) "Reef beds." This belt is marked by few outcrops and is almost entirely bare of vegetation except grass and scattered small juniper and oak trees. The rocks of this zone are well exposed only in the canyons, where they form thin beds of purplish shale steeply tilted and considerably fractured and distorted. At the base the beds of this member are almost invariably poorly exposed, but they seem to be somewhat sandy through a thickness of about 200 feet, as if representing a transition from the sandstone of the lower member. Above this transition zone the beds are fine-grained argillaceous and siliceous shale, usually finely comminuted, of a peculiar dark purplish-brown color, and similar to some of the shale in the upper member of the formation north of Coalinga. Many of the cracks in the shale are lined with sulphur. Toward the top the shale becomes in places, as near and southeast of Big Tar Canyon, of a yellowish or whitish color, and both siliceous and calcareous, the latter variety containing innumerable foraminiferal remains. These varieties bring out still more strikingly the resemblance to the shale member north of Coalinga and leave little doubt that the same horizon is represented in both localities. The thickness of beds exposed between the sandstone member of the Tejon and the Miocene varies from place to place along Reef Ridge. The maximum thickness that has been found is in the neighborhood of Canoas Creek, where it is about 1,000 feet.

Age and relations of the shale of the Tejon formation.—No very characteristic fossils have been found, either in the northern or in the southern parts of the district, in the shale overlying the sandstone known to belong to the Tejon formation, and therefore its classification with the Tejon is not final. It is considered as a portion of the Tejon (Eocene) because it is in apparent continuity with the beds of that age, because it is found in association with those beds wherever they occur, because it underlies unconformably beds containing fossils of lowest Miocene age, and because it contains fossils that point to its Eocene age. It is not thought probable that it belongs in the Oligocene, because rocks of that age have not been recognized in the Coast Range south of the Santa Cruz Mountains. The unconformity between this shale and the lower Miocene is profound in the Coalinga field. On Reef Ridge it is not apparent along the contact, but the tilting of the shale beds is in general steeper and the disturbance greater than in the Miocene above. At the northwest end of Reef Ridge the Vaqueros (lower Miocene) overlaps and rests directly upon the dark shale of the lower portion of the Knoxville-Chico, proving for this portion of the district, as well as the northern portion, the existence of an important unconformity between the Tejon and the Vaqueros. The variable thickness of the shale of the Tejon formation exposed along Reef Ridge indicates an overlapping of the Miocene upon different horizons, and the fact that the light-colored calcareous and siliceous shales that are characteristic of the uppermost horizon in the Coalinga field are absent in most places along Reef Ridge, though present in others, is a further proof of the existence of such overlaps.

Importance with relation to petroleum.—The shale in the upper part of the Tejon is thought to be the source of the petroleum found in the Coalinga district. The sandstone both above and below it is saturated and stained with oil, and although the shale itself does not give evidence of containing much petroleum it shows the effects of being stained by it. Petroleum has not been found in this district except in beds associated with the Tejon, and where the Tejon is absent the beds of the other formations are dry. Along Reef Ridge the sandstone of the lower half of the formation is saturated with oil, in places through its whole thickness. The sand has a strong odor and when a fresh fracture surface is exposed it is found to be stained brown throughout. Included layers of shale are stained purple. All the wells that are drilled through the shale to this sandstone strike oil in it in small amounts. The great thickness of the sandstone through which the oil has permeated lessens the probability of its being found in large amounts locally. It is probable that this oil originated in the shale above and became absorbed in the sandstones above and below. The occurrence of oil in the overlying Miocene beds will be mentioned later.

It is believed that the shale in the upper part of the Tejon contains a large proportion of material of organic origin. The calcareous facies is composed in part of foraminiferal remains, and the hard siliceous beds are very similar to the altered varieties of diatomaceous and foraminiferal shale found in other formations in other parts of the State. In places in this district the shale is softer and less altered and is composed largely of diatom remains. It is probable that these small marine organisms have been the chief source of the oil.

In other parts of California the origin of the petroleum is ascribed to formations of similar peculiar character, although of different age, and it is a striking fact that all the conditions point to the diatomaceous or foraminiferal nature of the deposits as the determining factor in the original occurrence of petroleum rather than to the age or other characteristics of the formations.

THE POST-EOCENE FORMATIONS.

General statement.—The Miocene, Pliocene, and early Pleistocene periods are represented in the Coalinga district by a series of formations that form a group by themselves, distinct from the older formations. The first impression received on viewing the field is that the later Tertiary beds form one continuous succession, and it is therefore natural to take up first a brief review of the whole series before passing to the more detailed description of the different divisions of it, which on closer study are found to be separable from one another.

The Miocene epoch was occupied in the Coalinga district by fairly continuous marine conditions. There was rapid erosion of areas of considerable relief situated probably along the line of the present mountainous belt, and deposition of the eroded material in great thicknesses in changing and, for the most part, slowly subsiding submerged basins. The formations thus deposited underwent disturbances during these periods, and were finally affected as a whole after the close of the Tertiary by the land movements, to which the greater part of the disturbance at present visible in the beds is due. As a result of these processes the periods following the Eocene are here represented by a great series of sandstone and shale and conglomerate beds, all tilted at about the same angle, having usually similar characteristics and presenting an almost perfect appearance of conformity and intergradation. By means, however, of discontinuous fossil faunas, distinguishable lithologic groups, the absence in some places, as a result of overlap, of formations or zones known elsewhere, and the appearance of fragments of older formations within younger ones, several important breaks, which prove the intervention of periods of time during which land conditions existed over wide areas or locally, may be definitely made out. The important post-Eocene formations that represent the epochs of submergence of the land in the area now occupied by the Coalinga district are the Vaqueros (lower Miocene), the Santa Margarita (upper middle Miocene), the Jacalitos (early upper Miocene), and the Etchegoin (late upper Miocene). The formation following these, the Paso Robles (Pliocene and lower Pleistocene), is probably in large part of different origin, but is similar to the others in the general features of its appearance. These formations are all united into one series in the monocline dipping down the east flank of Joaquin Ridge in the northern part of the district and again in the monocline dipping away from Reef Ridge in the southern portion, but the character of the series is not entirely the same in the two regions.

The series in the north.—In the northern part of the district the base of the Miocene-Pliocene is formed of coarse and fine oil-impregnated sands unconformably overlying the whitish and purplish petroliferous Eocene (Tejon) shales, these sands being overlain by prominent sandstone beds, by a prominent zone of white siliceous shale, and by soft sand, up to the base of a zone of bluish and variegated clay and sand locally known as the "Big Blue." Up to this point the beds are fossiliferous, have a thickness of about 550 feet, and are mapped as Vaqueros (lower Miocene). The "Big Blue" has a thickness of about 300 feet and is unfossiliferous. It is overlain by a thickness of about 175 feet of coarse sand and sandstone beds full of immense oysters, barnacles (*Tamiosoma*), scallop shells (*Pecten*), and other fossils, which beds may be named the *Tamiosoma* zone. This is overlain by 400 to 500 feet of sand and gravel beds up to the base of a very prominent gravel zone full of petrified wood. The beds from the base of the "Big Blue" up to this point are mapped as the Santa Margarita (upper middle Miocene) formation. The fossil-wood and gravel zone forms the base of a succession of sand, sandstone, gravel, and clay beds extending up to the base of a prominent zone of bluish-gray sand beds, having near their base a rich fossil bed (the *Glycymeris* zone). The succession of beds up from the base of the gravel zone to this point has a thickness of about 1,600 feet, and is mapped as the Jacalitos formation (early upper Miocene). The fossil bed and bluish sands immediately overlying grade upward into sand and clay beds, the whole forming a thickness of about 1,700 feet, which is mapped as the Etchegoin formation (uppermost Miocene), and this finally is overlain by poorly exposed coarse gravel deposits, which are mapped as the Paso Robles formation (Pliocene–lower Pleistocene). The total thickness of the succession in the Coalinga field thus outlined is about 4,600 feet, exclusive of the Paso Robles formation, which can not be measured in this portion of the district.

The series in the south.—In the southern part of the district the basal portion of the Miocene-Pliocene consists of about 700 to 900 feet of steeply dipping hard sandstone and conglomerate beds, forming the face of Reef Ridge. These overlie with an important, though usually not apparent, unconformity the shale of the Tejon (Eocene), and are locally petroliferous. At the summit they grade into softer beds overlain by hard siliceous shale. Up to this shale the beds are fossiliferous, and are mapped as the Vaqueros sandstone. The overlying shales are hard and whitish, form a prominent zone varying up to 1,200 feet in thickness, and are mapped as Santa Margarita, although only tentatively referred to that formation. These shales are overlain by a great succession of beds of sandstone, shale, sand, clay, gravel, and conglomerate of many varieties, having a thickness, as measured in a section south of Big Tar Canyon, of at least 9,500 feet, and presenting no prominent line of constant variation which may be taken as a separation between distinct terranes. This succession is, however, divided on the map, on the basis of criteria to be discussed later (pp. 40–61), into three approximately equal divisions corresponding to the formations in the north, namely, the Jacalitos (early upper Miocene), Etchegoin (uppermost Miocene), and the Paso Robles (Pliocene–lower Pleistocene). The total thickness of the Miocene-Pliocene and the lower Pleistocene measurable in the above-mentioned single section is over 11,000 feet.

VAQUEROS SANDSTONE (LOWER MIOCENE).

General description.—The unconformity at the top of the Tejon (Eocene) marks an important lapse of time before the beginning of the Miocene epoch. In the early Miocene a sedimentary formation was deposited in the Coalinga district that is the correlative of the formation known as the Vaqueros sandstone in the region nearer the coast. The contemporaneity of these formations is shown by the fact that the fossil remains of mollusks characteristic of lower Miocene time exist in both.

The Vaqueros sandstone in the area under discussion forms an elongated belt east of the belt of Tejon in the hills bordering the San Joaquin Valley. It consists of hard and soft sandstone, shale, and conglomerate, varying from 550 feet in the Coalinga field to 900 feet in the Kreyenhagen field, and may be easily distinguished from all other formations by the protruding tendency of the hard sandstone, known as the ''Reef beds,'' in its central portion. These beds outcrop prominently in the northern portion of the district, and again in the southern portion assume such prominence as to dominate the landscape on the bold face of Reef Ridge. They are much more resistant to erosion than the soft associated beds, and, dipping toward the valley on the northeast at an angle varying from 50° to 80°, they form the scarp and double row of pinnacles of Reef Ridge fronting the foothills on that side.

An important distinguishing feature of the Vaqueros is that the beds at its base are the chief oil sands of the Coalinga district. In many places they are saturated and discolored with petroleum. They rest upon the eroded surface of the shale of the Tejon throughout most of their extent, but overlap in the Alcalde and Jacalitos hills upon the Knoxville-Chico (Cretaceous) rocks, thus hiding the Tejon (Eocene) from view. Where such overlapping occurs, the basal beds lose their petroliferous character at a distance from the Tejon.

There are three different areas along the belt of outcropping Vaqueros which deserve separate description owing to the diversity of character assumed by the formation in them. One of these is in the oil field north of Coalinga, a second extends from a point in the Alcalde Hills west of Coalinga to Waltham Creek, and the third extends along Reef Ridge. The first two areas are separate. The second and third areas are shown on the map as discontinuous, but it is possible that a narrow belt of Vaqueros is exposed south of Waltham Creek, and that this connects with the belt on Reef Ridge.

North of Pleasant Valley.—In the hills north of Coalinga the formation includes all the beds overlying the Tejon at least as far up in the series as the base of the zone of fine grayish sand and clay locally well known as the "Big Blue," and possibly to the summit of this zone, which is at the base of the *Tamiosoma* zone. The "Big Blue" is not known to be fossiliferous and presents therefore no definite basis for correlating it, but it is mapped for the present as a portion of the overlying formation (the Santa Margarita) and the summit of the Vaqueros is placed at its base. The Vaqueros formation is thereby restricted to those beds which are known by their fossils to belong to it. Its thickness is about 550 feet.

The lowest bed of the formation is coarse, irregular, pebbly sand truncating the eroded edges of the Tejon formation. It is followed above by rough-bedded, hard and soft, both coarse and fine sandstone, sandy shale, and pure shale. These basal beds for 100 or 200 feet up are thoroughly impregnated with oil and have a dark-brown color due to staining, a strong odor, and a curious mode of fracturing characteristic of rock that is filled with bitumen. About 225 feet above the base is a hard zone ranging from 5 to 15 feet in thickness, made up of several calcareous sandstone layers and a rough mixture of ingredients of different kinds and textures. This zone of hard sandstone forms a prominent outcrop over the summit and down the sides of a hill just east of the road leading up Oil Canyon, appearing from a distance like a portion of the periphery of a huge wheel. Owing to the tendency of this bed to jut out over the surface of the hills, it was referred to as the "Reef beds" by F. M. Anderson,[a] and the name is here retained for convenience of reference.

Similar hard and soft sandstone beds continue to about 425 feet above the base of the formation, where a bed 10 to 20 feet thick of compact, white, diatomaceous and foraminiferal shale is sharply interbedded. This bed is prominent and so sharply marked off from the associated gray sand that it can be easily traced. It has been referred to throughout the field work as the "Indicator," and the name was found so convenient that it has been retained in

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[a] A stratigraphic study in the Mount Diablo Range of California: Proc. California Acad. Sci., 3d ser., Geology, vol. 2, No. 2, 1905, p. 175.

this report. The bed is continuous and in the same relative position everywhere, from Oil Canyon to the northern edge of the area shown on the map, beyond which no attempt was made to trace it. Southwest of Oil Canyon it is continuous for a mile or two at least. It preserves its strong individuality throughout in spite of the fact that it changes in character locally from a soft, compact, earthy deposit, both massively bedded and finely laminated (as on the eastern side of Oil Canyon in the south-central part of sec. 20) to a hard, thinly bedded, white, porcelaneous or flinty shale and yellowish calcareous shale (as south of the Laval grade on the hill (elevation 2,024 feet) 8½ miles north of Coalinga in the western half of sec. 21). This bed, where not greatly indurated, may be seen with a lens to be full of diatom remains—in fact, the rock seems to be chiefly composed of them. It is strikingly similar to the siliceous shale characteristic of the upper part of the Tejon (p. 23), and of the Santa Margarita formation of Reef Ridge (p. 37).

Above the "Indicator" bed soft gray and brown sandstones in thin layers make up a variable zone about 125 feet thick. This sandstone contains typical Vaqueros (lower Miocene) fossils, and is the uppermost horizon at which they are found. It grades above into soft, fine, grayish-white sand that looks bluish from a distance—the well-known "Big Blue." The latter zone being unfossiliferous, the line for the top of the Vaqueros formation is drawn at its base.

Southwest of Oil Canyon the Vaqueros beds become much thinner, and within about 2 miles they lose their prominence. In the hills for 2 miles north of the head of Pleasant Valley the beds are largely hidden by recent deposits of soil, alluvium, and gravel, but it is probable that a small thickness of beds, representing a part of the Vaqueros, is continuous. Their presence is doubtfully indicated by certain fossils that have been found.

Alcalde Hills.—In the hills west of Coalinga the Vaqueros is absent north of the San Joaquin coal mine, with the possible exception of a thin discontinuous zone locally exposed beneath the Santa Margarita and Jacalitos formations. South of the coal mine incoherent and extremely fossiliferous beds of the Vaqueros formation, largely of yellowish and gray sand, overlap upon the Tejon and Chico (Upper Cretaceous). Here, as in the Eastside field, they are about 500 feet thick. The sand is both coarse and fine, roughly bedded, and has partings and lenses of hard sandstone and gravel. Although it is fossiliferous, the fossils are poor and not certain as indicators. A section of the Vaqueros and overlying formations from Anticline Canyon to the Lucile oil well is given under the discussion of the developed territory (p. 101). Farther west a capping of low-dipping beds of this age extends over the ridges formed of steeply dipping beds of the Knoxville-Chico. This capping is, for the most part, only slightly indurated sand, clay, and gravel of many varieties of color and texture.

Jacalitos Hills.—Between Waltham Creek and the northern end of Reef Ridge the Vaqueros has not been recognized, but it may form a belt around the southeastern side of Curry Mountain, through the area tentatively mapped as covered by the Jacalitos formation, and thence continue southward, beyond the limits mapped, to join the belt on Reef Ridge.

Reef Ridge.—The Vaqueros overlies the shale of the Tejon on Reef Ridge and forms the steep face of the ridge. Southward from the region around Pleasant Valley the deposits thicken, and, owing to greater induration, form a more conspicuous part of the landscape than the contemporary beds farther north. Their relation to the underlying shale of the Tejon is probably unconformable, although no wide disparity in dip has been observed. There is even an apparent gradation from the shale below to the sandstone above in some places, making it difficult to determine the exact contact between the two formations. This difficulty is largely due to the lack of continuous exposures near the contact.

The Vaqueros is subject to considerable variation from place to place, as will be shown in the tabulated sections on page 35. It may in general be divided into three parts, one of comparatively soft beds of sandstone with shaly sandstone at the base, comprising about one-fourth of the total thickness; a second of hard, fossiliferous beds of sandstone with some conglomerate, making up about half of the formation and producing the prominent outcrops of Reef Ridge; and a third similar in thickness and character to the first and grading into soft, fine-grained beds that are poorly exposed and lead the observer to think there is a transition to the shale of the Santa Margarita formation above, although this is hardly supposable. The third part is much thicker on Canoas Creek than elsewhere, and there makes up half of the formation. The Vaqueros sandstone is thicker in the southeastern than in the northwestern half of Reef Ridge, the thickest section observed being 900 feet, on Canoas Creek. The middle part is marked by three principal horizons of hard fossiliferous sandstone and conglomerate beds, that stand out in strong relief. The lowest and middle beds are about 150 to 200 feet apart and the middle and uppermost beds 100 feet apart on the average. They vary in relative prominence from place to place and the exact horizon at which the induration is most pronounced is variable.

The following sections give an idea of the character of the Vaqueros as it occurs typically exposed along Reef Ridge:

Section of Vaqueros formation in Canoas Canyon.

	Feet.
Soft fine sandstone with large oil seepages; "Button beds" at base containing *Astrodapsis*, etc.; overlain by siliceous shales of the Santa Margarita formation	180
Hard and soft, gray and brown-stained sandstone, with large oil seepages in upper half	300
Massive sandstone beds with thick, very prominent hard beds at top and at base, the "Reef beds;" fossils at base	100
Sandstone with very prominent hard bed at base	200
Fairly hard, thin-bedded sandstone underlain by the Tejon formation	120
	900

Section of Vaqueros in Big Tar Canyon.

	Feet.
Soft sandstone and sandy shale, apparently a transition zone from Vaqueros to Santa Margarita	200
Two extremely hard fossiliferous sandstone and conglomerate beds, each about 10 feet thick ("Reef beds," with less prominent, softer sandstone between)	75
Coarse sandstone	150
Thin-bedded hard sandstone and shale, with reddish-brown shale at base	100
Massive, fairly soft grayish-brown sandstone	50
Soft sandstone with oil-stained streaks all through, overlying purple shale of Tejon; spring of tarry oil at base	200
	775

Importance with relation to petroleum.—The Vaqueros sandstone constitutes the principal reservoir for the petroleum in the Coalinga district. The oil enters the formation from the underlying Tejon and collects most abundantly in certain favorable zones within the formation, chiefly at its base, although permeating locally the whole formation in lesser amounts. The summit of the formation, as mapped, being overlain by the "Big Blue" north of Coalinga, it is coincident with the top of the productive zone in the Eastside field. Similarly it is believed that the productive zone in the Kreyenhagen field does not reach higher than the Vaqueros, the formation being there overlain by the impervious shales of the Santa Margarita. The relation of the formation to the occurrence of the petroleum is discussed more fully elsewhere. (See p. 69.)

SANTA MARGARITA FORMATION (UPPER MIDDLE MIOCENE).

General description.—A zone of beds full of very large fossil oysters and barnacles runs through the midst of the developed oil territory in the Eastside field and is well known to those familiar with the field. Its fossils show that it belongs in the same portion of the geologic column as the Santa Margarita formation[a] in San Luis Obispo

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[a] Fairbanks, H. W., Geologic Atlas U. S., San Luis folio (No. 101), U. S. Geol. Survey, 1904.

County, farther toward the coast. This formation belongs in the upper part of the middle Miocene. No fossils have been found in the beds immediately below or above the *Tamiosoma* zone, as the fossil beds referred to may be termed, from the typical and restricted occurrence in them of the large barnacle of that genus, but the beds below and above, for a thickness of several hundred feet, are for the present mapped in the same formation with the fossil beds because they are closely associated with them and to all appearances form a part of the same succession. The Santa Margarita formation is traceable only as far south as the San Joaquin coal mine. Beyond that the beds are either lacking or are unfossiliferous, so that it can not positively be stated that they are the same. In a region such as this, where the beds are so variable from place to place and the different formations so similar, the fossils furnish the only evidence of contemporaneity that holds good. In the Kreyenhagen field, therefore, where the portion of the series between the Vaqueros (lower Miocene) and Jacalitos (upper Miocene), corresponding to the portion occupied by the Santa Margarita farther north, is made up of unfossiliferous; hard, largely white, siliceous shales, it can not be stated definitely whether or not a continuation of the Santa Margarita occurs. The break in the geologic column between the Vaqueros (lower Miocene) and Jacalitos (upper Miocene) is great, covering the whole of middle Miocene time, and is represented only in its later part by the *Tamiosoma* zone and associated beds. The Monterey formation (early middle Miocene) of the region nearer the coast is lacking. It is possible that the beds overlying the Vaqueros formation in the two parts of the Coalinga district represent different divisions of the later part of the middle Miocene period, that in the Kreyenhagen Hills being perhaps later. The rocks in the two fields are for the present mapped as one formation, the Santa Margarita.

Coalinga field.—The basal part of the formation mapped as the Santa Margarita is the "Big Blue." This consists usually of about 300 feet of light-gray fine sand and clay that appears to have a light-bluish tinge, especially when moistened; locally it includes other materials, causing it to be one of the most varied zones in the region. It is recognized in the oil wells as a sticky and frequently tough sand and clay immediately overlying the oil sands. Toward the northern edge of the area mapped it becomes coarser and is made up largely of fine-grained, coarse-grained, and bowlder beds composed of serpentine fragments, evidently derived from an area of serpentine to which the basin of deposition was in close proximity. Some of these serpentinous beds are extremely hard and form prominent buttes in which the decaying serpentine presents a variety of shades of light blue, green, brown, and dark red.

The "Big Blue" is overlain by the *Tamiosoma* zone which comprises a thickness of about 175 feet of fossiliferous, fine, medium-grained and locally gray sand and some sandy clay. This in turn is overlain by 400 to 500 feet of alternating beds of fine sand, sandy clay, coarser sand, and gravel up to the base of the prominent and thick gravel zone considered as marking the base of the Jacalitos.

Toward the southwest the Santa Margarita formation disappears east of Oil Canyon, being overlapped by the Jacalitos. It is not known just where the overlap occurs, because the beds are poorly exposed and cease to have distinguishing characters. On the western side of Pleasant Valley the *Tamiosoma* zone reappears and overlaps directly upon the Tejon (Eocene) at the San Joaquin coal mine. This is the southernmost point at which the fossils of this zone have been found within the district, and south of there the *Tamiosoma* zone is either absent or overlapped by the Jacalitos formation. There is present, however, beneath the fossiliferous Jacalitos beds, between the coal mine and Waltham Creek, a zone of bluish and grayish clay, about 250 feet thick, mapped with the Vaqueros of that area, that may possibly represent the same horizon as the "Big Blue" in the Eastside field. If this be true, it indicates a closer relationship of the "Big Blue" to the underlying Vaqueros than to the Santa Margarita, with which this zone has been described. This zone is described in the geologic section from Anticline Canyon to the Lucile oil well, page 101.

Kreyenhagen field.—The Vaqueros sandstone all along Reef Ridge is overlain by a formation of purplish, white, and brownish siliceous and argillaceous shale, having a thickness varying between 50 and 1,200 feet. The thin sharp beds of shale dip steeply away from Reef Ridge to the northeast, their upturned edges being exposed in a belt, usually only a few hundred feet wide, that follows the face of the ridge. This belt is likewise a topographic feature, owing to the resistance of the beds, which produce a line of shoulders or knobs on the small lateral ridges descending toward the foothills. Southeast of Little Tar Canyon the ridge of the Pyramid Hills, composed entirely of the shale, is a still more marked expression of this topographic influence, which is likewise characteristic of the formation elsewhere. The features described make this shale easily recognizable as a lithologic unit with strong individuality, and distinguish its main portion markedly from the Vaqueros sandstone (lower Miocene) below and the soft sandstone beds of the Jacalitos (upper Miocene) above. As before stated, this shale is only tentatively referred to the Santa Margarita and may or may not have originated at the same time as the coarser beds in the Coalinga field. Fossils found a few miles to the northwest, in Waltham Valley, indicate that the shale belongs to the

Santa Margarita. The shale may be a deep-water equivalent of the coarser sediments in the Coalinga field, which at the northern end of the field are of a strikingly littoral nature.

Near the southeastern end of Reef Ridge and along the ridge of the Pyramid Hills northeast of Dudley the shale has a thickness of from 1,050 to 1,200 feet. It is divided into two main portions, the lower of which consists of harder, more siliceous, and more thinly laminated purple and white shale, and the upper of softer, more argillaceous, brownish shale. The lower portion is the more conspicuous, constant, and typical; the upper is not so well exposed, is more variable in character, and is not definitely separable from the soft sandstone and shale of the formation overlying. The following section is typical of the formation along the face of Reef Ridge at its southeast end, the different zones noted not being sharply separated from one another.

Section of Santa Margarita formation 3½ miles southeast of Big Tar Canyon.

	Feet.
Soft, brownish, clay shale poorly exposed, grading above into the fine sandy shale at the base of the Jacalitos formation and below into bluish-purple siliceous shale with occasional hard, more siliceous layers	400
Hard, siliceous, porcelaneous, thinly bedded shale, lavender colored, but weathering white, with prominent iron stain throughout along joints; breaking with angular and conchoidal fracture into elongated, sharp-edged pieces; interbedded with occasional soft laminæ	250
Fairly hard, purplish, siliceous and argillaceous shale, finely fractured into needle-like fragments with yellow calcareous concretionary lenses and interbedded porcelaneous layers; overlies the Vaqueros	400
	1,050

The two lower of these three zones differ largely in the proportion of hard beds that they contain, and, as this proportion is variable from place to place they do not form continuous belts distinct from each other. Together they make up the lower portion of the formation according to the division given above. The siliceous shale of the lower portion varies in amount of induration, ranging from a dull, opaque rock that may be scratched with the finger nail to a subvitreous flinty variety that can not be scratched by a knife. It resembles very strongly the altered varieties of shale of the Monterey formation (middle Miocene) that occurs nearer the Pacific coast, and the shale of the Tejon and the "Indicator" bed of the Vaqueros of this district. Like these, its less-altered varieties show traces of thickly embedded round dots and flakes that are almost certainly the remains of diatoms, and the shale has the characteristic flaky texture of diatomaceous material. The more siliceous shale seems to be made up almost entirely of the crushed diatom tests. It contains also fish scales and other particles of organic origin, but almost no molluscan remains. The shale laminæ are locally yellowish and calcareous and similar to the foraminiferal shale of the Tejon. Southeast of Little Tar Canyon the formation increases in thickness to about 1,200 feet, the increase being mostly in the brownish shale of the upper portion. The base of the formation is approximately at the axis of the anticline of the Pyramid Hills. The shale appears on both sides of McLure Valley with a general steep dip toward the valley and with little change in lithologic character or thickness.

The northernmost point at which the siliceous shale doubtfully ascribed to the Santa Margarita formation has been recognized in this district is at the northwest end of Reef Ridge, where the white shale forms a thin zone between the underlying and overlying sandstone formations. It has a thickness of only about 50 feet. On the west side of Jasper Canyon, the Vaqueros is overlain by hard, brittle, yellowish-brown and black clay shale that may be a continuation of the Santa Margarita, but its relations have not been studied. A zone composed in large part of shale continues in the same position in the series at least as far as the main valley of Jacalitos Creek, to the northwest. This zone is highly tilted and much broken up.

Southeastward along Reef Ridge the shale thickens gradually and continuously. Southwest of the head of Zapato Creek there is about 200 feet of shale that is divided into two zones of about equal thickness. The lower one is of siliceous shale weathering purplish, brownish, and white, similar to that forming the prominent outcrops of this formation elsewhere. The upper is of purplish and brownish largely clay shale. This grades at the top into alternating beds of brown sandstone and dark clay shale, which make up a thickness of several hundred feet and which may or may not be a part of the same formation. It is possible that this sandstone and shale correspond to part of the thickness of shale found farther southeast, but, fossil evidence being lacking, the formation is restricted for the present to the beds that are purely shale. The most rapid thickening of the formation takes place between Zapato Canyon and Canoas Canyon. At the latter it is about 650 feet thick and comprises three almost equal zones—the lowest of fine-grained purplish shale of medium hardness, fractured into fine, needle-like, angular fragments; the middle of hard, siliceous white shale; and the upper of soft brownish shale.

The same siliceous shale is found south of the Coalinga district, extending along the border of the San Joaquin Valley. It thickens from the northwest end of Reef Ridge toward the south until at the Temblor ranch, in western Kern County, it attains the remarkable thickness of 5,400 feet. It is probable that a part of the formation here stands for a period of time not represented by deposits in the region of Reef Ridge and may coincide with a part or all of the Monterey formation (middle Miocene). The thickening of the shale southward may take place at its base, the beds in the Coalinga district representing an unconformable overlapping of the upper portion upon the Vaqueros.

Importance with relation to petroleum.—In the Coalinga field the Santa Margarita formation has an important relation in different ways to the occurrence of the petroleum. In the Eastside field its base is taken as extending down through the "Big Blue." This zone caps the Vaqueros sandstone, or productive zone; and although small amounts of oil and tar are found above its base, there is none in commercial qualities. The Santa Margarita is of chief importance here as forming an impervious capping which has held the oil in. In the Westside field the formations are thinner, and sand beds of the Santa Margarita become part of the productive zone. In the Kreyenhagen field the shale of the Santa Margarita acts, as the "Big Blue" does, as an impervious capping that keeps the oil confined within the Vaqueros beds.

JACALITOS FORMATION (EARLY UPPER MIOCENE).

Definition and general description.—The formation overlying the Santa Margarita in the Kreyenhagen Hills consists of about 3,600 feet of sand, gravel, clay, and sandstone, in places very fossiliferous, and was formed in the earlier upper Miocene time. It is here named the Jacalitos formation owing to its characteristic exposures both north and south of the creek of that name. Abundant and well-preserved fossils, by means of which its age is determined, occur in the type locality. It is probably the equivalent of parts of one or more of the upper Miocene formations known in other parts of the State, but its definite relations to these have not yet been worked out. It is in part represented in the northern portion of the district by similar beds aggregating a much smaller thickness.

In the fields this formation does not stand out prominently as a lithologic or stratigraphic unit and is not readily distinguishable by itself. On the contrary, it forms merely a portion of the great thickness of apparently conformable Tertiary beds that are exposed in the great monocline, dipping at medium and high angles toward the valley. The formation may be roughly distinguished as that portion of the series between the shale of the Santa Margarita below and the major beds of blue sand that are characteristic of the lower part of the formation above it (the Etchegoin) throughout the district. The Jacalitos, however, includes a great thickness of blue-sand beds at its summit in the southeastern part of the Kreyenhagen Hills. A feature of this formation is the occurrence at intervals in it of hard zones that project like saw teeth and by their resistance protect the beds immediately above and below them, thus forming long parallel ridges. The same feature is in a greater measure characteristic of the Vaqueros sandstone and Santa Margarita formation below and less so of the Etchegoin (uppermost Miocene) formation above. Another feature of the Jacalitos is the great number of sand and pebble beds, full of sea urchins, that are found in all parts of the formation. This feature is likewise one belonging to the formation above. The most important features, however, and the only ones that can be relied upon to separate the Jacalitos from the other sandy formations, are the position that it occupies in the series and the various fossils that it contains.

The Jacalitos in the Kreyenhagen Hills is probably unconformable with the Santa Margarita below, although the two formations appear conformable at the contact, the line between them being arbitrarily drawn where the beds that are predominantly shale (Santa Margarita) give place to sandy beds (Jacalitos). In the northern part of the district the relation of these two formations appears also to be one of conformity, although the overlap of the Jacalitos on the Santa Margarita near Oil Canyon proves clearly that it is the opposite. The line there also is drawn arbitrarily at the base of the prominent pebble zone full of fossil wood. The Jacalitos is likewise conformable to all appearances with the later Miocene (Etchegoin) beds which rest above it and are largely similar in composition, the line between these two formations being likewise drawn somewhat arbitrarily, chiefly on the basis of the fossil contents. There is a possibility that an unconformity between these two formations exists in the hills surrounding Pleasant Valley. (See p. 49.)

From its locality of typical occurrence in the Kreyenhagen and Jacalitos hills the Jacalitos formation extends southwestward into McLure Valley, where it occupies a similar position between the underlying Santa Margarita and the overlying Pliocene sands. Toward the northwest it reaches into the interior of the Diablo Range through the depression formed by the Waltham syncline and toward the north extends across Alcalde Canyon into the region around Pleasant Valley. North of Jacalitos Creek it no longer rests upon the shale of the Santa Margarita, that formation being lacking, and the Jacalitos ceases to be completely represented. The question of the relations of the beds of this age in the northern and southern portions of the district is complex and can be decided only on the basis of detailed paleontologic evidence. The formation will be considered separately for the areas lying to the south and to the north of Waltham Creek.

South of Waltham Creek.—From Jacalitos Creek southward the Jacalitos formation affords more complete exposures than elsewhere. The type locality for its fossils is along that creek, near which representative faunas have been collected at several different points from different horizons, but the undisturbed monocline in the range of the Kreyenhagen Hills furnishes somewhat better sections of the formation as a whole, since it has suffered considerable disturbance along Jacalitos Creek and in the hills north of it. Moreover, in the latter region the base of the formation does not appear within the area shown on the map and has not been definitely traced. As before stated, the alternating beds of brown sandstone and dark shale that overlie the siliceous shale of the Santa Margarita about the head of Zapato Creek and thence westward are mapped with the Jacalitos, although it is uncertain to which formation they properly belong.

The following tabulated sections will give the best description of the lithologic character of the Jacalitos formation and its zones. It must be borne in mind, however, that the formation is variable from place to place; that any single description applies merely to a single locality; that the different zones noted are not sharply separable, but grade into one another, all containing elements in minor quantity common to the others, and that a great variety of sedimentary beds occur that would necessitate almost endless discussion to describe in detail. Although the formation is thus variable, part of the variation noticeable in the sections may be due to the fact that exposures are not complete and that beds and fossils apparent in one place are frequently hidden in others. It is especially difficult to determine the relative quantitative importance of clay or somewhat compacted shale, for the reason that the firmer sand beds are better exposed and therefore appear to dominate, and because it can not always be determined whether the softer unexposed beds are fine sand or clay.

The following is a section of the Jacalitos along Jacalitos Creek, from the summit of the formation, at a point on the south side of the creek and at the north base of the 1,220-foot hill in the eastern part of sec. 31, T. 21 S., R. 15 E., to its contact with the prominent Vaqueros sandstone at a point not shown on the map, about 1½ miles west-northwest of the end of Reef Ridge, in the middle of sec. 11, T. 22 S., R. 14 E.

Section of Jacalitos formation on Jacalitos Creek.

	Feet.
Bluish to brownish-gray clay and clayey sand, alternating with light-gray and olive-gray pebbly sand, with occasional hard fossil layers and with *Pecten estrellanus* bed at base; overlain by blue sand at the base of the Etchegoin..	750
Massive beds of buff and olive-gray sandstone and sandy clay interbedded with thin and thick beds of olive-gray pebbly sandstone and gravel, and occasional sandstone layers. Sand dollars (*Echinarachnius*) numerous throughout, usually in the pebbly layers. Bed of dark-brown sandstone at base (at forks of Jacalitos and Jasper creeks), containing a rich fauna, including *Chione*, *Macoma*, *Panopea*, *Echinarachnius*, etc....................	1,300
Alternating heavy beds of coarse gray and brown sandstone and thin beds of fine sandstone and sand of the same colors, with some beds of gritty olive-gray sandstone and hard fossil layers. Bed with large *Astrodapsis* 200 feet above base. Probably the zone of *Trophon* found farther southeast......	500
Alternating beds of grayish and brownish sand and sandstone, with some sandy clay and fossil layers in the sandstone..................................	750
Alternating beds of soft gray and brown shale and sandstone, much tilted and fractured, and in part overturned..................................	500+
	3,800+

The basal portion of this section rests upon the continuation of the steeply tilted Vaqueros sandstone that is so prominent on the face of Reef Ridge. Shale similar to the typical shale, mapped as Santa Margarita, is entirely lacking; but it is possible that the much disturbed basal zone of this section is the equivalent of that shale. It may be the continuation of the similar thickness of alternating beds of brown sandstone and dark shale overlying the typical shale of the Santa Margarita along Zapato Creek, which has been mentioned (p. 42) as doubtfully referred to the Jacalitos instead of to the Santa Margarita formation. There is a possibility that this zone of alternating beds, which is for the present considered as the basal portion of the Jacalitos, may be unconformable with the main body of that formation, but further work will be required in order to determine this.

The middle portion of the Jacalitos formation, in this locality especially, contains large unconsolidated accumulations of fine pebbles, some in thick beds by themselves and some interbedded in thin layers in the sand beds or scattered throughout the sand. These coarse beds are frequently fossiliferous, and sand dollars are especially abundant in them.

The uppermost beds of the above section underlie the lowest of a number of prominent blue-sand beds that are characteristic of the landscape in this district along the belt of Etchegoin (Pliocene) formation. The line of contact between the Jacalitos and Etchegoin formations is drawn somewhat arbitrarily on the basis of this lithologic break and of the characteristic *Mytiloconcha* and *Glycymeris* fauna that occurs in a bed just above. The beds above and below this line of contact dip with perfect conformity at an angle of about 25°.

The following is a section along Canoas Creek from the top of the Jacalitos, immediately south of the house of Hugo Kreyenhagen, to its contact with the Santa Margarita:

Section of Jacalitos formation along Canoas Creek.

	Feet.
Chiefly grayish sand and soft sandstone, with thick pebbly zone containing *Pecten estrellanus* at base; fossil bed with *Cardium, Solen, Echinarachnius, Macoma, Nassa, Olivella,* etc., at top	650
Chiefly massive gray and buff-colored coarse-grained sand; a prominent bed of friable dark sandstone with *Panopea*, etc., at base	1,000
Similar sand, with prominent ridge-forming bed at base	350
Similar sand, with prominent bed, the zone of *Trophon*, etc., at base	400
Similar sand, with occasional sandstone layers and with prominent sandstone bed at base, forming first hill northeast of Reef Ridge	500
Similar sand, grading below into sandy shale, overlying the Santa Margarita	600
	3,500

Southeast of Canoas Creek the Jacalitos formation preserves a character and thickness very similar to that given in the above sections.

The fossiliferous sandstone beds become more indurated, so that they stand out like sawteeth on the summits of longitudinal ridges most of the way to Big Tar Canyon and form very pronounced features of the landscape. As this canyon is approached the beds assume steeper and steeper attitudes until they dip uniformly at angles varying between 50° and 60°. The chief new feature assumed by the formation in this region is that some of the sand and pebble beds in its higher portion have the blue color characteristic of the basal beds of the Etchegoin. Confusion is thus introduced into the separation of the two formations, but the same paleontologic criteria used in distinguishing them elsewhere still hold good here. In the neighborhood of Garza and Big Tar creeks the zone of blue sands extends down over 800 feet into the Jacalitos, whereas farther southeast, as shown in the next section, it extends to a still lower horizon, the lowest at which it has been found anywhere. The exact similarity of the beds above and below the contact of this formation with the overlying Etchegoin, together with their perfect angular conformity, is almost conclusive evidence of their actual conformity and continuity.

Southeast of Big Tar Creek the beds begin to lose prominence and to form nearly uniform rolling hills of soft sand, with few large exposures. The dip in this region becomes uniformly about 60°. The following section shows the character of the formation at about the farthest point southeast in the Kreyenhagen Hills at which a section of satisfactory completeness can be obtained from the surface exposures:

Section of Jacalitos formation on north side of Reef Ridge 3½ miles southeast of Big Tar Canyon.

	Feet.
Dark-gray sand with about 20 feet of light-blue sand at base	120
Olive-gray sand with light-blue sand at base; the basal portion is probably the main *Pecten estrellanus* zone found 1 mile northeast	350
Fine shaly yellowish-gray sand, with whitish-gray and dark-gray layers interbedded and some bluish pebbly sand; the lowest blue sand is at base	720
Compact, medium-grained to coarse gray sand, like beach sand	275
Olive-gray speckled sand and soft sandstone with appearance of a pepper-and-salt mixture	275
Interbedded fine and medium grained grayish, whitish, and yellowish sand and speckled sand like the last, with some clay layers	600
Fine and medium grained reddish, yellowish, and grayish sand and soft sandstone with white sandy clay at top and coarse pebbly sand 300 feet below top; grading at base into soft whitish-gray sandy shale	1, 200
	3, 540

The Jacalitos is worn off over the summit of the Pyramid Hills anticline but reappears on its southwestern flank on the north side of McLure Valley, dipping under the alluvium of the valley floor. The descriptions of the formation already given apply to it as it appears in this region. The exposures are in general poor.

The succession of beds exposed on the western flank of the high hill 1 mile southeast of Alcalde, east of the road leading southward from Alcalde toward Jacalitos Creek, comprises about 1,600 feet of sand, clay, gravel, and fossiliferous sandstone up to the base of the blue beds that mark the Etchegoin formation. Locally, on the flank of this hill the beds have a slight stain resembling that due to the presence of oil. West of this road above mentioned the Jacalitos beds are chiefly sand, with some clay and gravel and with fossils. They overlap upon the steeply tilted Cretaceous strata and are warped into a number of low plunging folds. Still farther west the Jacalitos overlaps a wide extent of country in the Waltham syncline, along which it has been traced 6 miles west of the area shown on the map along Jacalitos Creek as far as the road to Stone Canyon.

Alcalde Hills.—North of Waltham Creek the Jacalitos formation loses the great thickness that characterizes it throughout its occurrence to the south, retaining a thickness of only about 800 feet. This thinning takes place very rapidly in the immediate vicinity of Waltham Creek, as it does in the case of the Etchegoin formation as well, indicating that the lower portion of Alcalde Canyon follows a line that has been an extremely important locus of orogenic movements. The areas to the north and south thus separated have had in large measure a different geologic history. The exact nature of the thinning that takes place in the Jacalitos has not been determined; whether it is a constant thinning affecting all of the beds of the formation or whether it is due to the absence of some large parts of the formation, owing either to their having never been deposited north of Waltham Creek or to their having been worn away, is not known at present. It is believed that the area north of Waltham Creek was land during the earlier part of Jacalitos time and that the lower portion of the formation was never deposited there.

The formation over the area of the Alcalde Hills retains the general character of the beds to the south. It is a variable formation of incoherent yellow, brown, and gray sand, sandstone, clay, and gravel, locally containing fossils such as *Pecten estrellanus*, *Pecten oweni*, a large species of *Metis*, and a large sand dollar of the genus *Echinarachnius*. The typical fauna of the lower part of the formation in the type locality along Jacalitos Creek is not present. The beds are evidently of near-shore origin, being in many places roughly bedded, cross-bedded, and variable. They are full of gypsum. The base of the formation as mapped is a fossiliferous bed, containing *Pecten estrellanus*, and other fossils, that is traceable southward from the San Joaquin coal mine to Waltham Creek. It is underlain, conformably so far as known, by a zone of clay and fine sand about 300 feet thick, which has been mentioned before (p. 37) as possibly belonging to the Santa Margarita but which is mapped with the Vaqueros. The summit of the Jacalitos formation is mapped at the base of the *Glycymeris* zone, which is the equivalent of the basal Etchegoin as found elsewhere. The relation of the beds along this contact is also conformable so far as observed. A section of this and the associated formations will be found on page 101.

North of Pleasant Valley.—The beds correlated with the Jacalitos in the northern part of the district form that part of the series on Joaquin Ridge which lies between a prominent zone of gravel at the base that outcrops typically on the hill (where the tanks are situated above the Standard Oil Company's wells, on the west side of the NE. ¼ sec. 28, T. 19 S., R. 15 E.) and the base of a zone of gray sand with abundant fossils outcropping typically on the hill where one tank stands, in the NE. ¼ SW. ¼ sec. 34, T. 19 S., R. 15 E. This portion of the series consists of about 1,600 feet of alternating fine gray sand and clay, pebbly and medium-grained sand and sandstone, and gravel. The basal pebbly zone has a thickness of about 150 feet, of which the lower half is a solid layer of pebbly gravel, locally hardened to conglomerate, and the upper half thin-bedded, brown, gray, and in some places pinkish, sandstone and sand intermingled with pebbles and with occasional shaly layers. This zone contains a great abundance of petrified wood in large fragments, and at one place a tooth of an extinct species of horse was found in it. The rest of the formation is mostly soft, fine sand, with which hard sandstone layers, pebbly sand, and sandy clay beds are frequently interbedded. Several pebbly zones have considerable thickness, but no part of the upper portion has distinct individuality or prominence, and very few fossils have been found in it.

Importance with relation to petroleum.—The Jacalitos formation is not petroliferous in the Eastside field in the northern part of the district, but is very productive in the Westside field owing to the thinning out of the formations between it and the Tejon. In the Kreyenhagen field it is not known to be productive at any point, no oil having escaped from the Tejon and Vaqueros through the shales of the Santa Margarita. The thickness and character of the Jacalitos throughout the district have an important bearing on the question of the accessibility of the oil, owing to the fact that most of the wells have to penetrate it in order to reach the oil sands at depths at which they will be productive. A knowledge of its thickness has been especially useful in making calculations as to the depth at which the oil sands may be found in the Kreyenhagen and Kettleman hills.

ETCHEGOIN FORMATION (UPPERMOST MIOCENE).

Definition and general description.—The name Etchegoin was applied by F. M. Anderson[a] to a great thickness of beds of unconsoli-

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[a] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California: Proc. California Acad. Sci., 3d ser., vol. 2, No. 1, 1905.

dated sand, gravel, and clay, characteristically blue at the base, occurring typically in the vicinity of the Etchegoin ranch, 20 miles north of Coalinga, and extending continuously from there both northwest and southeast along the border of the Diablo Range. In accordance with Mr. Anderson's statements and on the basis of the reasons stated below the Etchegoin formation is mapped and described in the present paper as the succession of slightly consolidated beds of sand, gravel, and clay occurring on the summit and flanks of Anticline Ridge and on the southeast end of Joaquin Ridge north of Coalinga, above the base of the hill-forming sandstone beds (referred to for convenience as the *Glycymeris* zone), and below the beds described as the Paso Robles formation. Strata in other portions of the Coalinga district are referred to the Etchegoin formation on the basis of paleontologic correlation with the beds on Anticline Ridge.

The *Glycymeris* zone is an extremely fossiliferous bed of somewhat indurated sand that forms the summit of the hill at the northwest end of Anticline Ridge (in the NW. ¼ SW. ¼ sec. 34, T. 19 S., R. 15 E.) and extends continuously from that point along the line mapped as the base of the Etchegoin formation. It is underlain at the locality referred to by clay that is classed in the Jacalitos formation and is overlain by a thick succession of bluish-gray sand beds interbedded with dark-gray sand. The zone affords almost perfect specimens of many species of fossils that make up a distinctive fauna. It is called the *Glycymeris* zone for ease of reference, because it is an important datum line that may be recognized by the association of fossils contained in it.

There are various reasons for assuming this zone to be the base of the formation. First, an unconformity is known to occur below it in the synclinal basin north of White Creek, for there a zone containing the same fauna rests directly upon Cretaceous (Chico) sandstone, and somewhere between Oil Canyon and the Cretaceous area an unconformable overlap of the *Glycymeris* zone upon the underlying Tertiary beds must exist. It is therefore appropriate to consider the beds above the base of the *Glycymeris* zone as a distinct formation, although on Anticline Ridge and in the greater portion of their extent in the region north of Coalinga, as well as to the south as far as they have been studied, they appear to rest conformably upon the beds below. A further reason for assuming this zone as the base is that it is at the bottom of a succession of bluish sand beds on Anticline Ridge and at some other places in the Coalinga district, thus marking a sharp and easily recognizable variation in lithology between the beds below and above it. At other places, however, especially in the southern portion of the Kreyenhagen Hills, the blue sands occur also far below the *Glycymeris* zone, so that the lithologic feature can not be relied upon everywhere as a basis of separation.

In the description of the Jacalitos (early upper Miocene) frequent reference has been made to the overlying Etchegoin (late upper Miocene). In fact, these formations are so closely related and so similar that the one can not well be described without reference to the other. In places they seem to have originated as a chronologically continuous succession of marine deposits and are only arbitrarily separable, whereas in other places an overlap of the latter upon the former has taken place. Many of the features of structure, influence on topography, and lithologic variability mentioned in connection with the former exist also in the latter.

The Etchegoin formation consists of slightly consolidated sand, clay, and gravel, interbedded with occasional indurated beds, and is characterized by an abundance of invertebrate fossils, among which a few forms like sand dollars (*Echinarachnius*), barnacles (*Balanus*), *Mulinia, Arca, Mya*, small oysters, *Neverita*, etc., are particularly prevalent. It reaches a thickness of over 3,500 feet in the southern portion of the district, but in the northern portion it is at most only half as thick. It may be most easily recognized by the dominant grayish-blue color of the massive sand beds that comprise a thickness of several hundred feet at its base, but an examination of its characteristic fossils is the only means of distinguishing it accurately from the associated formations.

One of the most important of its broad features in the Coalinga district is the usual predominance of coarse material, such as sand and pebbly deposits, in its lower portion, and of finer material, such as extremely fine sand and clay, in its upper portion; but this feature is characteristic in various degrees according to the locality, and in some places is hardly noticeable.

Coalinga field.—In the oil field north of Coalinga the Etchegoin has a thickness of about 1,700 feet. The basal *Glycymeris* zone has already been described. Several other fossiliferous beds occur within several hundred feet above this, and contain abundant sand dollars (*Echinarachnius*), barnacles (*Balanus*), cardiums, turritellas, etc. The lower portion of the formation is composed largely of beds of compact coarse and fine blue sand alternating with zones of pebbly sand, fine gray sand, and some clay, with occasional more hardened beds. The clay increases toward the upper part of the formation, being interbedded with unconsolidated light-gray sand that spreads over the surface and obscures the structure. The formation occurs in the low hills bordering the valley and passes beneath the alluvium of the floor.

The Etchegoin forms a belt along the edge of the Alcalde Hills west of Coalinga and is overlapped by the recent valley deposits. A good section of it is obtainable 2 miles southwest of Coalinga, where the fossiliferous beds of the *Glycymeris* zone at its base outcrop on the west side of the summit of a prominent hill on which a tank is situated, in the SE. ¼ sec. 1, T. 21 S., R. 14 E. These beds are of yellowish gypsiferous sand and sandstone of fine to medium grain, with a thickness of about 200 feet. They are overlain on the top of the hill by 200 feet of both loose and indurated coarse gravel, pebbly sand, and interbedded fine sand containing sand dollars. Above these beds comes a thickness of 250 feet of whitish-gray sand of the texture of granulated sugar, grading at the base into coarser even-grained sand. This zone is followed above by about 20 feet of coarse sand, sandstone, and pebble conglomerate containing many fossils, including *Pecten wattsi*, *Arca*, *Ostrea* (small), sand dollars, sea urchins (*Astrodapsis*), etc. This is the zone of *Pecten coalingaensis* that occurs in the Kettleman and Kreyenhagen hills. (See p. 50.) The highest beds exposed are of fine yellowish and whitish-gray sand comprising a thickness of about 50 feet, these being overlain by the surface deposits at the base of the hills. The thickness of the formation in this section is about 700 feet, but as the uppermost beds that belong above the *Pecten coalingaensis* zone are hidden, the whole formation probably has a thickness of about 900 or 1,000 feet.

White Creek basin.—A detached area of Etchegoin beds is preserved in the syncline near the head of White Creek, northwest of Coalinga, where the formation rests upon the beds of the Cretaceous (Chico). At one time these beds were doubtless continuous with those of the same formation around Pleasant Valley, and their presence in this interior basin proves that an extended overlap of the Etchegoin over the older Tertiary formations and onto the Cretaceous took place.

The basal beds appearing above the Cretaceous in this syncline are very fossiliferous and contain a finely preserved fauna exactly similar to that of the *Glycymeris* zone on Anticline Ridge. They may be regarded as representing the same horizon. The lowest 100 feet of beds immediately overlying the Cretaceous are composed of coarse and pebbly, compact but soft, yellowish-gray sandstone hardly distinguishable from the underlying Cretaceous sandstone. These beds are not very fossiliferous, but grade upward into beds largely composed of fossils, with a matrix of yellowish-gray sand. *Arca* is the most abundant genus, but *Glycymeris*, sand dollars (*Echinarachnius*), and locally many other forms are also very abundant. The bulk of the formation in its middle portion consists of similar sand and sandstone resembling the massive upper Cretaceous sandstone and containing occasional fossil beds. Numerous layers of very hard sandstone and some concretions are present. The beds for a few hundred feet below the top of the formation are more variable, a thick zone of coarse pebbles being followed above by alternating beds of sandy shale, calcareous shale, and coarse and fine sand

and sandstone, and, near the top, a hard and prominent thin bed of dark-brownish sandstone full of small white fossils. The total thickness of the formation is about 1,100 feet, which corresponds fairly well with the thickness that it is supposed to possess in the hills west of Pleasant Valley.

Kreyenhagen Hills.—The best and most complete sections of the Etchegoin may be found in the Kreyenhagen Hills, where the upturned northeastward-dipping beds of this formation are exposed as a belt in the foothill area between the Jacalitos and the Paso Robles. It is not easily separable from these two formations, the line at the base being especially arbitrary. The contact at the base of the Etchegoin is drawn below a fairly constant fossiliferous zone, supposed to be the equivalent of the *Glycymeris* zone north of Coalinga. The contact at the top of the formation is marked by the usual occurrence above it of the gravelly beds of the Paso Robles, by the presence at the top of a zone containing *Mya, Ostrea*, etc., which may be called the upper *Mya* zone, and by other more local criteria.

The zone of blue-sand beds at the base of the formation is constant throughout the Kreyenhagen Hills. Its thickness is variable from place to place and is of little value except for broad correlations. The lower part of the formation is composed chiefly of sandy beds of all degrees of coarseness up to pebble beds, and of many varieties of blue, gray, and drab color, with minor amounts of clay. The upper part of the formation is composed of alternating thick zones of sand and clay, the amount of clay being somewhat greater than in the lower portion.

There are four main fossil zones in the Etchegoin of the Kreyenhagen Hills, corresponding to similar ones found in other parts of the district. The lower zone is the *Glycymeris* zone already mentioned. About 800 feet above the base of the formation, roughly speaking, comes a zone characterized by an abundance of *Mulinia* (large), *Arca*, sand dollars (*Echinarachnius*), etc., which may be referred to here and in the Kettleman Hills as the upper *Mulinia* zone, as it is the uppermost bed in which large specimens of this genus are found. This zone is usually coincident with the upper portion of the blue-sand zone. The third main zone may be called the *Pecten coalingaensis* zone, owing to the nonoccurrence of this species at other horizons. It is within 300 to 400 feet below the top of the formation and contains a well-preserved and extremely varied fauna, including *Pecten coalingaensis* and *Pecten wattsi* as about the most typical forms, together with many sand dollars, sea urchins, brachiopods, etc. The fourth zone includes the summit beds of the formation, which contain *Mya, Ostrea*, etc., and which are called the upper *Mya* zone. These four zones do not include all the important fossil beds in the formation, but are those that have been found most persistent and easily recognizable and therefore most valuable as datum lines.

The following columnar sections of the formation in different parts of the Kreyenhagen Hills give a tabulated description of the formation as it occurs typically and convey an idea of the variability of the beds:

Section of Etchegoin formation on Zapato Creek.

	Feet.
Light-gray and olive-gray sandy clay and sand, with sandstone layers at top containing *Mya*, *Ostrea*, *Arca*, *Neverita*, etc.; the upper *Mya* zone; overlain by gravel of Paso Robles formation	300
Olive-gray fine sand and pebbly sand, with thin sandstone layers. Rich fossil zone at top containing *Pecten wattsi*, *P. coalingaensis*, brachiopods, sea urchins, etc.; the *Pecten coalingaensis* zone	400
Bed of light-blue sand, the highest of the blue-sand zone	10
Massive beds of gray sand and sandy clay with occasional thick beds of blue sand; a bed containing *Arca* in quantities at the base	290
Similar gray and blue beds with a 20-foot zone at base composed of massive, olive-gray, compact sand containing many inconstant laminæ of hard brownish-gray sandstone	850
Gray sand	350
Prominent bed of cavernous-weathering blue sand	50
Alternating thick beds of gray sands and bluish clay, with thin layers of sandy clay, and with three prominent beds of blue sand in the lower 100 feet. This basal portion is probably the upper *Mulinia* zone	250
Olive and light-gray sand and sandy clay	500
Prominent beds of blue sand at top and base, with prominent massive beds of olive-gray medium-grained and pebbly sand and minor beds of clay and blue sand between; this is the base of the blue-sand zone and approximately that of the Etchegoin	475
	3,475

Section of Etchegoin formation on Canoas Creek.

Fine gray sand and clay with occasional hard layers; zone of *Mya*, etc.; overlain by gravel of Paso Robles formation	450
Gray sand and clay in alternating beds of variable thickness	1,700
Top of blue-sand zone; massive gray sand both coarse and fine, interbedded with clay in lesser amounts and occasional heavy beds of blue sand; contains numerous sand dollars and a zone at the base with *Mulinia*, *Cardium*, *Glycymeris*, *Mytiloconcha*, etc.; the upper *Mulinia* zone	550
Similar beds to the base of the zone of blue sand. Beds at base containing sand dollars (*Echinarachnius*) *Solen*, *Cardium*, *Nassa*, etc	900
	3,600

Section of Etchegoin formation 3½ miles southeast of Big Tar Canyon.

Thinly bedded hard white porcelaneous shale, with whitish-gray fine sand, pebbly sand, and sandy clay, containing lenticular layers and nodules of porcelaneous shale and many bone fragments	250
Alternating thick zones of whitish-gray sand and clay	1,080
Solid zone of thin-bedded pebbly sandstone	45
Whitish-gray sand and clay with a 15-foot bed of coarse pebbly sand in middle	660

	Feet.
Prominent beds of compact gray sand with softer sand and sandy clay between; whitish gray sand with black pebbles at base	210
Compact fine gray sand streaked with layers of fine whitish sand and sandy clay.	420
Compact, slightly gritty white shale somewhat similar to the Santa Margarita	10
Solid zone of gray sandstone, coarse pebbly sandstone, and hard calcareous shale	40
Fine gray sand	50
Highest bed of blue sand, with a 10-foot layer of pebbles at base and a 3-foot layer full of sand dollars, barnacles, arcas, etc., 20 feet above base; probably upper *Mulinia* zone	80
Interbedded blue sand and sandy clay with a prominent 20-foot bed of blue sand at base; probably the zone of *Crepidula*, *Solen*, etc., found 1 mile to the northwest	120
Minor beds of blue sand, with a thick zone of hard calcareous shale in middle	90
Prominent blue-sand bed, pebbly toward the base and containing many sand dollars	90
Soft gray sand	70
Very prominent blue sand	40
A prominent 30-foot bed of blue sand at base overlain by bluish and gray sand and three less prominent beds of blue sand	250
	3,500

McLure Valley.—The Etchegoin probably outcrops over a small area in the Avenal syncline in McLure Valley above the Jacalitos formation, and is characterized at its base by blue sands, but it can not be definitely recognized. The thickness of beds above the Santa Margarita in this region is so great that some Etchegoin must be present in addition to the Jacalitos. No fossils have been found, and there is no direct evidence on which to base a separation between the two formations, so that the line of contact mapped is arbitrary. The highest beds appearing in the syncline, which are taken to be the basal beds of the Etchegoin, consist of blue sands. Above these everything is covered by the recent alluvial deposits of the valley.

Kettleman Hills.—The Etchegoin is excellently exposed in the Kettleman Hills, where it is a thick formation similar in character to the same terrane in other parts of the district. Its lower portion appears along the axis of the Coalinga anticline, but although the lowest beds that the plunging anticline brings to the surface are very nearly the basal beds of the formation no underlying formation is known to be exposed. The uppermost beds appear all around the Kettleman Hills and are everywhere overlain, with apparent conformity, by the fresh-water beds at the base of the Paso Robles. The greatest thickness that has been found exposed is in the south-central part of the hills, on the southwestern flank of the anticline, where the beds below the fresh-water horizon measure over 3,000 feet.

Different horizons in the Etchegoin of the Kettleman Hills afford good datum lines that may be recognized by means of the characteristic faunas and the constancy of the beds containing them, and it is convenient to designate these briefly, beginning with the summit of the formation as a constant datum line and going down. The summit of the formation is marked, as it is in portions of the Kreyenhagen Hills, by a constant fossiliferous zone of sand and sandstone interbedded with dark clay, which here, as in the Kreyenhagen Hills, may be called the upper *Mya* zone, because of the great abundance of fossils of the genus *Mya*. It is also full of other fossils, small yellow *Littorina* and small oysters being especially common. This zone has a thickness varying between 200 and 300 feet, and is prominent in the topography because it usually forms a line of hills. In the southern part of Kettleman Hills it forms the main ridge. Below it comes a zone of uneven thickness, usually measuring about 700 feet, which in some portions of the hills is composed almost entirely of fine inky-blue clay, and in others of clay and sand interbedded in varying proportions. Toward the base of this zone, usually between 700 and 900 feet below the top of the formation, there is a zone of fossiliferous sandstone beds equivalent to the zone of *Pecten coalingaensis* occurring in the Kreyenhagen Hills. The beds at this horizon likewise show a tendency to form hills or knobs, but these are not so prominent as those of the upper *Mya* zone.

Below this the formation is largely sand and clay, chiefly sand, down to the base, the lower portion here, as elsewhere, being composed of beds of ordinary sand alternating with beds of blue sand. The next prominent fossil bed contains *Mya* in large quantities, and will be referred to as the lower *Mya* bed. It occurs between very prominent beds of blue sand on the summits of hills; and in the north-central portion of the Kettleman Hills forms the main ridge. Owing to the fact that the formation is thicker in the southern than in the northern portion of the hills and apparently thicker on the western than on the eastern flank of the anticline, the distance below the summit of the formation at which this and other beds occur can not be stated as a constant. The variation of this zone is between about 1,900 and 2,400 feet below the summit. One of the fossils most in evidence in the Kettleman Hills is the large *Mulinia;* a bed containing abundant specimens of this species occurs about 100 feet below the lower *Mya* bed. It is the highest horizon at which the large specimens have been found, and is with little doubt the upper *Mulinia* zone of Kreyenhagen Hills. In the northern portion of Kettleman Hills it is near the base of the exposed series, and is the lowermost easily recognizable zone; in the central portion of the hills it still persists, but lies above exposed beds of considerable thickness. Another zone in which *Mulinia* occurs very abundantly in Kettleman Hills is between 500 and 700 feet below the upper one, and may be referred to as the *Glycymeris* bed, for the reason that it contains an association of fossils, including *Mytiloconcha*, *Glycymeris*, etc., similar to the bed so named north of Coalinga. It is about the lowest bed exposed, and is approximately at the base of the Etchegoin formation.

The following sections represent fairly well the lithologic character and variations of the Etchegoin in the Kettleman Hills. Variability is the rule, and it would be difficult to find any two sections in which the same beds are exposed and the characteristics are constant:

Section of Etchegoin formation on southwest flank of Kettleman Hills, along road 6 miles from northwest end of hills.

	Feet.
Yellowish-gray sand and clay, with some dark clay; many fragments of porcelain shale on surface; small oysters in sand at top, and yellow calcareous shale lenses in bluish-black clay at base; upper *Mya* zone	125
Alternating beds of fine drab gypsiferous sand, sandy clay, and drab to bluish clay, with occasional sandstone layers, and with a bed at the base containing delicate fossils, *Nucula*, etc	250
Similar beds, with layers of iron-stained sandstone at base	115
Similar gypsiferous beds, with light-colored sand predominating; the *Pecten coalingaensis* zone should be here somewhere, but was not found	250
Inky-blue clay with minor beds of sand and with a hard 1-foot bed of yellow limestone in middle	290
Fine sand and some light and dark clay, with hard, very gypsiferous, yellow and variegated sandstone at the top, and interspersed hard layers below; sandstone with *Solen*, etc., near base	135
Highest blue-sand bed	45
Grayish-blue massive sand and pebbly sand, with fossils	130
Thinly and massively bedded drab and light-gray sand with occasional beds of blue sand and layers of inky-blue clay, white clay, and pebbles; the sand at base is the lower *Mya* bed	550
Massive beds of blue and gray sand, with *Mulinia*, etc., at base; upper *Mulinia* zone	100
Less prominent beds of blue and gray sand with sand dollars, oysters, etc	300
	2, 300

On the northeastern flank of the anticline in this same portion of the hills the beds are repeated with approximately the same thickness, but the section measured made it appear that there was possibly a slight thinning on that side.

The next section is on the southwestern flank of the anticline in the south-central portion of the hills, beginning at the 1,030-foot hill on the main ridge in the center of sec. 3, T. 23 S., R. 18 E., and extending northeastward across the strike of the beds to the anticlinal axis.

Section of Etchegoin formation on southwest flank of Coalinga anticline in central portion of Kettleman Hills.

	Feet.
Inky-blue clay below fresh-water bed	50
Yellow and gray sand, full of fragments or nodules of porcelain shale and of fossils, *Mya*, *Macoma*, *Solen*, *Ostrea*, *Arca*, *Littorina*, etc.; the upper *Mya* beds	200
Inky-blue clay zone; sandy beds at top containing innumerable small oysters; occasional layers of yellow calcareous shale; a thin bed, 15 feet above base, of coarse purple and yellow, iron-stained, and exceedingly gypsiferous sandstone with many fossils, probably the *Pecten coalingaensis* zone	725

	Feet.
Mostly light-gray and drab sand, with beds of dark clay in minor amount; a pebbly sand layer 200 feet below top; pebbly sand and iron-hardened sandstone layers near base	1, 400
Blue-sand zone, several massive beds of blue sand and pebbly sand interbedded with fine light-gray and drab sand, sandy shale, and pebbly sand and occasional iron-hardened beds; at top is probably the upper *Mulinia* zone; the basal sand is full of fossils, *Mulinia*, *Mytiloconcha*, *Glycymeris*, etc., and is the lower *Mulinia* zone	675
	3, 050

As may be inferred from an examination of these two sections, the anticline plunges from the locality of the second toward that of the first, and a much greater thickness of beds is exposed in the second. The upper *Mulinia* zone occurs 2,000 feet below the summit in the first, whereas the bed that has been correlated with it in the second occurs over 300 feet lower. It seems probable from this and similar instances in other sections that the formation thickens toward the south between the top and this bed, the thickening being similar to that which takes place between the oil field north of Coalinga and Kreyenhagen hills. It may reasonably be assumed that a thickening takes place also below the upper *Mulinia* zone, and that the base of the formation is not so far below this zone in the northern portion of the hills as farther south.

Toward the northern end of the hills, as shown by the map, the Etchegoin plunges completely beneath the Paso Robles formation and does not appear again until brought up by the oppositely plunging anticline on Anticline Ridge. Toward the southern end of the hills the formation becomes covered more and more by surface sand and soil, and both its zones and structure are obscured. At the southern end of the hills it does not pass below the Paso Robles, but exposes beds not far above the base.

Importance with relation to oil.—Nowhere within the Coalinga district is the Etchegoin formation known to contain any petroleum, but, like the Jacalitos, it has an important relation to the question of accessibility of the oil. Some wells in the Coalinga field pass through a considerable portion or the whole of this formation before reaching the Jacalitos or lower formations. All wells drilled around the edge of Pleasant Valley, or on Anticline Ridge, or in the Kettleman Hills, will have to pass through this formation, and its thickness must be taken into account in calculating the depth of the oil sands. The great increase in thickness that takes place in this and the other post-Eocene formations south of Waltham Creek has an all-important bearing on such calculations.

PASO ROBLES FORMATION (PLIOCENE-LOWER PLEISTOCENE).

Definition and general description.—The Etchegoin is overlain along the border of the valley by a thick terrane of beds of gravel, sand, clay, sandstone, conglomerate, and some limestone that forms the uppermost member of the series of upturned formations exposed in the monocline on the eastern flank of the Diablo Range. It differs materially from the formations so far described in that its origin is doubtful, being in part fresh water, in part marine, and in large part probably of subærial origin. In the Kettleman Hills, where these beds are best exposed, the basal sand, which appears to lie conformably upon the marine bed at the top of the Etchegoin, contains many fresh-water fossils. The beds above this have a thickness of several thousand feet, and as far as observed are unfossiliferous except at one horizon near the summit at which a few marine fossils have been found. Along the foothills of the Diablo Range in the Coalinga district the basal fresh-water beds have not been recognized and may be lacking. Gravel and sand beds belonging to the same series overlie the Etchegoin with local appearances of unconformity.

This whole series of tilted beds overlying the Etchegoin is referred to here and mapped as one formation, the Paso Robles, for the reason that it appears to be a continuous succession and can not be consistently subdivided in different regions. It was formed without doubt under varying conditions of deposition, but it may or may not represent a continuous period. It began to be formed in some portion (probably the earlier portion) of the Pliocene epoch, and probably represents a continuation of deposition well into the Pleistocene. Its summit may be considered as the highest bed markedly affected by the great uplift that took place early in Pleistocene time throughout the Coast Range region, and as unconformably overlain by the more recent horizontal terrace deposits and alluvium.

The highest portion of the formation exposed appears near the edge of Kettleman Plain in the south-central part of the Kettleman Hills, but the summit of the formation as above defined is not exposed. It is probable that the edge of the hills there marks the approximate summit of the tilted beds. The formation may be recognized most easily by the fresh-water fossils and strange bone beds at its base, by its position overlying all the other formations and bordering the valley, and by the prevalence in it of prominent beds of bowlder gravel, which is much coarser and more abundant than in any of the other Tertiary formations. Otherwise this formation resembles some of the others closely, and it is frequently difficult to differentiate them.

This formation is called Paso Robles, because it is the same as the formation which spreads over the summit of the Temblor Range south of Polonio Pass, the divide between the Antelope and Cholame valleys, and from there southward to the Palo Prieto Pass, and which may be traced thence to Paso Robles in the Salinas Valley, where it was named by H. W. Fairbanks.[a]

The formation in the type locality consists of a thickness of at least 1,000 feet of slightly coherent conglomerate, gravel, sand, and clay in stratified deposits that have been locally tilted to moderate angles and that lie unconformably upon the marine Pliocene and older formations. The formation is unfossiliferous and is believed by Fairbanks to be of fresh-water origin.

Kettleman Hills.—The Paso Robles is completely exposed only in the Kettleman Hills, and its occurrence there forms the basis for most of the discussion given here. As shown on the map it occupies an almost complete fringe around the hills, dipping steeply away on the flanks of the anticline which exposes the Etchegoin beneath. Throughout the Kettleman Hills the Etchegoin and Paso Robles are apparently conformable, and in places, especially toward the northern end of the hills, there are indications that a gradual change took place toward the end of the deposition of the former, that shallow-water marine conditions gave way to brackish-water and this in turn to fresh-water conditions. The upper *Mya* beds are constant at the top of the Etchegoin and contain a fauna that with the possible exception of one species, *Littorina,* is indicative of estuarine conditions. And these beds, in some places at least, grade into the fresh-water beds above.

The thickness of the basal fossiliferous zone of the Paso Robles is usually no more than 60 to 100 feet, although it is as much as 300 feet on the southeastern side of the Kettleman Hills a few miles northeast of Avenal Gap. The beds consist principally of fine-grained earthy sand, very gypsiferous, and frequently containing many scattered pebbles. The fossils are entirely fresh-water forms and occur in places very thickly embedded. Along a part of the northeastern side of the hills certain layers are so indurated as to form hard limestone and to produce a ridge marking the contact between the Etchegoin and the Paso Robles formations. Associated with the fresh-water beds are abundant small bones that have not been identified. They are characteristic of this zone, but have been found also in association with marine fossils in a bed many hundred feet below the top of the Etchegoin. The only fossils found in the Paso Robles at a higher horizon than the basal zone are noted in the second tabular section below (p. 59). A few good specimens of these and many fragments were found in two beds of coarse pebbly sand 15 feet apart in the upper portion of the formation.

Above the basal zone the formation consists of a continuous unvaried succession of alternating zones and beds of unconsolidated light-gray

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[a] Geologic Atlas U. S., San Luis folio (No. 101), U. S. Geol. Survey, 1904.

and yellowish fine sand, sandy clay, light and dark clay, coarse darker gray sand, and gravel and bowlder beds, and occasionally interbedded layers of hard sandstone. The whole series is gypsiferous. The beds are usually fairly thick and massive and the bedding planes not very pronounced, although in some places the strata are sharp and square cut. Frequently the stratification and the dip appear more distinct from a distance than from near at hand. Many of the coarse sand and gravel deposits are roughly stratified and exhibit lenticular structure, grading within a short distance into finer deposits. In general, the formation resembles very closely the recent alluvial deposits and is almost indistinguishable from them except by means of the disturbed position of its beds.

A marked feature of the gravel is the predominance in it of subangular fragments of hard white siliceous shale, derived presumably from the shale either of the Tejon or of the Santa Margarita. This shale is very resistant and lends itself remarkably to preservation in younger deposits of gravel and débris. The other pebbles and bowlders in the gravel beds of the Paso Robles are of many different Coast Range types of rock and have probably been derived chiefly from the Diablo Range. Many of them are angular and have been subjected to little wear before being deposited. Rocks of a granitic type are very common, and the area also contains serpentine, porphyries of different kinds, different varieties of basic igneous rocks, both fresh and considerably altered, jasper, sandstone, conglomerate, quartz, schist, etc.

The lower beds of the Paso Robles in the Kettleman Hills are as a rule not of very coarse material, although pebbles are scattered through them. The first important zone of coarse gravel appears several hundred feet above the base. It is associated with several beds of hard sandstone, and in consequence shows a marked influence on the topography, forming a hill on each of the lateral ridges descending from the summit to the valley. This zone probably occurs at a slightly variable horizon, ranging from about 500 to 800 feet above the base of the formation. It is in general higher toward the south in the hills, and may thus indicate a thickening of the formation in that direction. Above this zone occur various other prominent gravel zones.

The following columnar sections represent fairly well the character of the formation in that part of the Coalinga district in which it is most completely exposed. In each place the section was started at the edge of Kettleman Hills, but beds were not found exposed for about 700 feet into the hills away from the edge. In this border area the beds almost certainly have a fairly steep dip, and it would be conservative to add at least 150 feet to the total thickness given to represent the summit beds there.

The first section was made on the southwest side of the hills, about 9 miles northwest of Avenal Gap, and is as follows:

Section of Paso Robles formation 9 miles northwest of Avenal Gap.

	Feet.
Mostly fine, earthy, drab and yellowish-gray, faintly bedded massive sand, with occasional roughly aggregated beds and lenses of pebbles and bowlders; the stratification bedding is very apparent from a distance	500
Similar beds of hard and compact straw-colored massive sandy clay, with partings of gypsiferous sandstone	300
Similar clay interbedded with pure sand, gravelly sand, and sandstone layers, with a hard sandstone bed at base	75
Compact, drab, gray, and straw-colored coarse and fine sand	200
Thin layers of gravel and coarse sands, with a bowlder bed several feet thick at base	75
Pure fine sand similar to that above, with hard sandstone layers	125
Mostly gravel, composed in large part of fragments of hard, white, siliceous shale, interbedded with sand and sandy clay, and with hard sandstone beds at top and base	75
Alternating beds, from a few inches to 1 or 2 feet thick, of loose and compact fine sand, roughly bedded slightly gritty clay, pebbly sand, gravel, and hard usually purplish sandstone; some of the sand is speckled all over with inclusions of hard, white siliceous shale, and the gravel is largely composed of it	225
Pure clay and sandy clay	75
Fine clay and sand at top, grading down to coarse sand and pebble and bowlder beds at base; some fine drab sand forms hard, massive, roughly laminated beds.	75
Drab sand with some pebbles and with gravel and hard sandstone beds at base	150
Sand and clay and a few hard sandstone beds	375
Gravelly sand	100
Loose earthy sand full of pebbles, bowlders, and fragments of white siliceous shale, and containing fresh-water shells, and bones; at the base is a sharp change to the dark clay and upper *Mya* beds of the Etchegoin	50
	2,400

The following section was made on the southwestern flank of the Kettleman Hills, along the Dudley-Lemoore road, which crosses about 4 miles northwest of Avenal Gap:

Section of Paso Robles formation along Dudley-Lemoore road.

	Feet.
Massive 1- to 3-foot beds of well-compacted but not indurated fine sand, clayey sand, clay, coarse sand, and gravelly sand, with several beds, many feet thick, of coarse gravels and bowlders in the middle and at the base. Much gypsum occurs in fine particles and as a filling in cracks, causing hardening in individual beds and in spots. Some sand and gravel beds are lenticular. One hundred feet below top are two coarse sand beds, 15 feet apart, containing *Ostrea* and *Littorina*, marine fossils	400
Yellowish-gray earthy sand, sandy clay, and clay in well-defined massive beds with some pebbly sand	650
Dark clay	75
Thick zone of pebbly sand	150
Chiefly dark clay	150
Yellowish-gray fine sand yielding whitish surface sand	75
Pebbly sand	70

	Feet.
Sandy clay	80
Chiefly fine gray sand, alternating with pebbly sand, sandy clay, and clay; a thick zone of pebbles and bowlders occurs about 350 feet below the top	1,100
Chiefly fine gypsiferous ashlike light-gray sand, with dark clay layers and many large pebbles scattered through, but no prominent gravel beds; lower portion is the fossiliferous fresh-water zone, but no fossils were here found; it overlies dark clay and *Mya* beds at the top of the Etchegoin	350
	3,100

Kreyenhagen and Jacalitos hills.—The Paso Robles beds dip under the Kettleman Plain and reappear on the western arm of the syncline along the border of the Kreyenhagen and Jacalitos hills. As in the Kettleman Hills, the formation dips more steeply and exposes a much greater thickness toward the south, but here this difference is even more pronounced. The beds have a dip of only a few degrees northwest of Zapato Creek and form a comparatively narrow belt to where they are finally overlapped by the alluvial deposits of Pleasant Valley. South of Canoas Creek the Paso Robles beds rise to extremely steep dips, appearing almost overturned in places, and cover a wide belt. They are, however, very poorly exposed. The formation here consists of deposits similar to those in the Kettleman Hills, but the basal fossiliferous beds have not been found. The formation is chiefly characterized by its heavy gravel deposits, which, contrary to the rule in the Kettleman Hills, in places rests directly upon the Etchegoin, forming high hills fronting the valley. This occurrence of heavy bowlder deposits near the base has led to the theory that possibly the fresh-water basal zone is lacking and that a higher portion of the Paso Robles has overlapped upon the Etchegoin. Northwest of Zapato Creek a distinct unconformity between the Paso Robles and the Etchegoin is shown to exist by the fact that the gravel beds of the former overlap upon the Etchegoin and locally cover up some of the higher beds of that formation. Southeast of Big Tar Canyon the basal portion of the Paso Robles is sand and clay and is marked by a zone of white nodular shale beds, interbedded with sand, containing the strange bones mentioned before as occurring in the fresh-water beds in the Kettleman Hills. The Etchegoin and Paso Robles appear conformable in the southern part of the Kreyenhagen Hills. The latter has a thickness of at least 2,000 feet and probably much more.

Guijarral Hills.—In the northern part of the Coalinga district the Paso Robles is doubtless continuous beneath the valley floor but does not appear exposed except in the Guijarral Hills, which are entirely covered by deposits of coarse gravel of this formation, the name of the hills being derived from this feature. The beds are almost horizontal but appear to dip slightly toward Pleasant Valley and Polvadero Gap, giving the surface of the hills the appearance of a plane inclined in those directions. The beds are exposed by the Coalinga anticline and probably belong in the lower middle portion of the formation. They may be traced northward on the east flank of Anticline Ridge, but are throughout this region poorly exposed. The contact with the underlying Etchegoin can not be definitely traced nor the relations of the two formations determined.

Importance with relation to petroleum.—The Paso Robles formation does not come in contact with the oil-bearing formations and contains no traces of oil. Over most of the area in which it occurs it is separated by so great a thickness of deposits from the productive zones that its mere presence is usually sufficient to indicate the inaccessibility of the oil. Around the border of Pleasant Valley and on Anticline Ridge and the Guijarral Hills, however, productive wells may later be put down through this formation.

TERRACE DEPOSITS AND ALLUVIUM.

The later Pleistocene and recent periods are represented by a mantle of alluvium and terrace deposits covering the floor of the Great Valley and the large side valleys, and extending over the bottom of most of the smaller valleys and canyons and the lower slopes of the foothills. The larger areas of these deposits are shown on the map (Pl. I, in pocket) in white. In the large valleys it is probable that these deposits have a thickness of several hundred feet, as the late period has been largely one of aggradation. Elsewhere the deposits are merely superficial. All of the smaller valleys show evidences of several terraces along their sides, these being especially evident along Zapato Creek, where at least seven terraces may be counted. Many of these terraces are covered with stream gravel and sand. The greater portion of the whole region under discussion is covered by surface soil and residual sand derived from the soft formations. All of these comparatively recent deposits are similar in materials and appearance to the underlying formations and are not easily distinguishable from them. They have the effect of obscuring the main facts of the geology over large areas.

IGNEOUS ROCKS.

The only igneous rocks occurring within the Coalinga district are associated with the Franciscan formation. The Cretaceous, Tertiary, and Quaternary formations were not affected by igneous intrusions, and there is no evidence that there was volcanic activity in this or the adjacent regions during these periods. The serpentine that has already been mentioned as covering such a wide region in the heart of the Diablo Range originated as an intrusion of basic igneous rock into the Franciscan sedimentary formation before the beginning of the period in which the Knoxville and Chico formations were laid down. Many different varieties of it occur, varying from hard, little-altered peridotite, in which the constituent crystals are well displayed, to much-metamorphosed and surficially altered serpentine and related minerals.

Toward the head of White Creek a hill formed of a hard hornblende-bearing igneous rock seems to have been intrusive into the serpentine. It is a soda-bearing syenite, of a variety heretofore undescribed, and varies from an extremely fine-grained to a porphyritic facies in which there are large, perfect crystals of hornblende. The area of this rock as shown on the map is slightly exaggerated in size.

STRUCTURE.

Some of the broad features of the structure of the Coalinga district have been briefly touched on in the preceding discussions of the topography and geology. The structural axes and the general attitude and succession of the strata are outlined on the map (Pl. II), and therefore merely a general review of the whole and the discussion of certain particular points is necessary here.

CROSS STRUCTURES AND THEIR TOPOGRAPHIC INFLUENCE.

The structure of the Diablo Range is, broadly speaking, anticlinal, and its eastern flank is composed of a great monocline of sedimentary strata dipping toward the San Joaquin Valley. But the regularity of this monocline is broken by its being thrown into a series of waves and offsets by various important as well as minor plunging anticlinal and synclinal folds, and by faults that run in various directions both parallel with and oblique to the main structural trend of the mountains. This main trend parallels the general course of the Sierra Nevada, the Coast Ranges, and the coast in this portion of California, and is approximately N. 35° W. to N. 40° W. The general orientation of the secondary structural axes is considerably more to the west of north than this. These show their influence prominently in the topography by producing the oblique spurs and valleys discussed under the subject of the topography. The same features, both topographic and structural, may be observed south of the Coalinga district and also in the mountainous tracts west of it. It is due to such structures that the Gabilan Range converges and joins with the Diablo Range in the latitude of the Coalinga district; and the various discontinuous spurs of the high and complex portion of the Diablo Range, which are arranged in positions en échelon with one another, may be explained on the same basis. It would appear therefore that the region has been subjected to two main sets of compressional forces, the one set acting on a line running roughly

N. 50° E. and the other set being along a line running N. 20° to 30° E., making a counter-clockwise angle toward the north of about 20° to 30° with the former set.

PERIODS OF MOVEMENT AND THE EFFECT ON FORMATIONS OF DIFFERENT AGES.

A large part, if not the major part, of the movement that has resulted in the disturbance of the Tertiary beds in this region, and of the Cretaceous beds over considerable areas in which they were not previously greatly disturbed, took place in Pleistocene time after the deposition of the Paso Robles (Pliocene-Pleistocene) formation. This feature of the history of the region is indicated by the fact that the later Tertiary and early Pleistocene formations appear to have been disturbed almost as much as the older ones, and in some places as much as the Cretaceous beds. An example of this is found in the beds exposed in the Coalinga anticline, which dip gently and would hardly appear to have been folded at all previous to the time in which the Etchegoin (Pliocene) beds were tilted on the same anticline to the vertical position. It is certain that important movements were taking place during Cretaceous and Tertiary time, notably at the close of the Tejon (Eocene) period of deposition, when the beds of that age were uplifted and greatly disturbed before the subsidence that allowed the deposition of the Vaqueros (lower Miocene) beds on their eroded surface, and also at the close of the Vaqueros period. The fact that all the formations from the Cretaceous to the lower Pleistocene appear in places to be conformable in dip, and that at least the Miocene, Pliocene, and later deposits almost invariably appear so, indicates that the whole series was affected as one during the Pleistocene by extraordinarily severe disturbances.

In the Tertiary formations the land movements have resulted chiefly in folding rather than in faulting. The strata of these formations are everywhere tilted at angles ranging from a few degrees to the vertical and are locally overturned, but evidences of faulting are by no means as frequent. The older formations, on the other hand, are much faulted as well as folded, and many faults occur in them that have not been mapped. The Knoxville-Chico (Cretaceous) rocks exposed along Los Gatos Creek afford an excellent example of the very great number of large and small faults occurring along a fault zone such as that which determines the position of this old valley.

It has been pointed out in the description of the formations how they vary in thickness within short distances. This variability is a characteristic feature of the geology of the region. In the post-Eocene formations it may be explained on the theory that the gradual subsidence which took place during the different periods progressed more rapidly toward the south than it did in the northern part of the Coalinga district, where the shore line must have been near, and that the periods of land conditions interrupting the progress of sedimentation were more prolonged and frequent in the northern region.

The number of mutually unconformable formations present in the Coalinga district proves that the region was undergoing almost continuous movements. The unconformities are rarely very apparent at the contact between the formations, and the fact of the existence of unconformable relations is usually to be made out only from a detailed study (1) of the areal distribution of the formations, which gives a clue to the presence of overlaps, and (2) of the fossils, which indicate time breaks. The evident angular unconformities are between the Vaqueros (lower Miocene) and Tejon (Eocene) at various localities, between the Tejon and the older Cretaceous shale at points on Reef Ridge, between the Vaqueros and Cretaceous in the Alcalde Hills and on Juniper Ridge, between the Santa Margarita (upper middle Miocene) and Vaqueros where the Castle Mountain fault zone crosses Reef Ridge; between the Santa Margarita and Tejon at the same point and also at the San Joaquin coal mine, and between the Santa Margarita and Cretaceous along the north and east sides of McLure Valley. Somewhat more doubtful is the apparent discrepancy between the Paso Robles (Pliocene-Pleistocene) and Etchegoin (upper Miocene) north of Zapato Creek. Elsewhere the formations, even those profoundly distinct in age, generally appear conformable in dip.

Overlaps of all of the Tertiary formations, except the Paso Robles, upon the Cretaceous occur within the Coalinga district, thus proving their mutual unconformity. Except in the overlap of the Etchegoin on White Creek and of the Vaqueros in the Alcalde Hills over the upper Cretaceous (Chico) sandstone these overlaps take place over the lower portion of the rocks mapped as Knoxville-Chico. The variability of the formations in original areal extent and in thickness, lithologic character, and structure within small areas gives an indication of the local activity of the disturbing forces which have continued to act within this region.

MAIN LINES OF STRUCTURE.

Coalinga anticline and syncline.—Among the individual features of the structure in the Coalinga district the Coalinga anticline is next in importance to the general monocline on the eastern face of the Diablo Range. This anticline is one of the principal oblique structures of the range. It forms Joaquin Ridge and plunges toward the valley, exposing in turn the Franciscan formation at the head of

Joaquin Ridge and all of the subsequent formations. The synclinal axis of its plunge occurs at Polvadero Gap, beyond which it is undoubtedly continued by the anticline plunging in the opposite direction, which causes the beds to dome up into the Kettleman Hills. At the southern end of these hills, about a mile south of the area mapped, the anticline does not plunge beneath the surface of the valley again as might be expected by analogy. On the contrary, it exposes a fairly low portion of the Etchegoin formation and the hills are left incomplete, their cessation being due to erosional removal rather than to structure, as at the northern end. The Lost Hills, which are situated within 10 miles south of the edge of the area shown on the map, have not as yet been studied, but it is a probable supposition that they are due to a continuation of the Coalinga anticline. The length of this within the district is 60 miles. Its principal features are its alternating plunges in different directions; its curving course, indicating a complexity in the forces which have acted upon it; its asymmetry, and its broad summit and steep flanks. The steep dips on its southwestern flank north of Coalinga, as compared with the gently dipping summit and northeastern flank, are very pronounced. Similar asymmetry is observable in the northern part of the Kettleman Hills, although the divergence in dip on the two flanks is not so great, the usual maximum dip being 35° to 45° on the southwest and 25° to 31° on the northeast. The Coalinga syncline is the parallel supplementary feature and forms the topographic depression of Pleasant Valley and Kettleman Plain. Like the anticline, it plunges southeastward from Joaquin Ridge and rises again opposite the Kettleman Hills. West of Oil City it dies out in low dips on the flank of the anticline.

The folds and faults forming the other main spurs of the Diablo Range in this district have already been mentioned in the discussion of the topography.

Los Gatos and White Creek basins.—The structure in the basin of Los Gatos and White creeks between Joaquin and Juniper ridges is peculiar and complicated. A broadly folded anticline of Cretaceous beds with a locally sharp axis plunges southwest and northeast off the flanks of these two ridges toward the lower part of Los Gatos Creek, where it is crossed by a broad syncline plunging both northwestward into the axis of the White Creek basin and southeastward into Pleasant Valley. The syncline becomes sharply defined and regular along White Creek where it incloses a remnant of Etchegoin. Toward Pleasant Valley it broadens out to form part of the general monocline dipping toward the axis of the Coalinga syncline. A complicated set of faults occurs along Los Gatos Creek, where the upper sandstone of the Cretaceous (Chico) near the axis of the syncline on its southwestern side is faulted down into contact with the older Cretaceous shale beds on the southwest side of the main fault line. The movement has been in the nature of a flattening of the axis of the syncline toward its head, resulting in the formation of branch faults on the downthrow side and greater and greater throw in the successive blocks toward the southeast. Many small faults occur that have not been shown on the map, and there are doubtless other large ones that have not been observed. The basin of Los Gatos and White creeks has probably been an axis of movement along which successive disturbances have taken place during a long period.

Alcalde Canyon.—Another old zone of movement is represented by the southeastern face of Curry Mountain and the lower part of Alcalde Canyon from Alcalde toward Pleasant Valley, and possibly likewise out across the valley toward Polvadero Gap. The region north of this zone has had in some respects a different history from that to the south, and it is difficult to correlate the features of the geology in the regions so separated. To the south the formations have a far greater thickness, the upper sandstone (Chico) portion of the Knoxville-Chico rocks is lacking, the shales of the Santa Margarita(?) appear and gradually thicken and are only doubtfully to be correlated with the Santa Margarita formation to the north, and a great thickening of the Paso Robles formation is steeply tilted and well exposed.

Jacalitos Hills.—Between Alcalde and Reef Ridge there is a depressed area occupied by comparatively low, rolling hills that represents the structural continuation of the old synclinal basin of Waltham Valley. The syncline of that valley plunges toward the southeast and dies out just within the area mapped on the general monocline dipping away from Reef Ridge. This monocline is regular except for some low, broad, plunging folds that throw it into undulations northwest of Zapato Creek, among them being the Jacalitos anticline and syncline. A noteworthy feature of the Jacalitos anticline is that it plunges in both directions into the flank of the Jacalitos syncline.

Castle Mountain fault zone.—The main structural features of the southwestern part of the territory mapped are the Castle Mountain fault zone, Pyramid Hills anticline, Avenal syncline, and Diablo anticline. The Castle Mountain is a very important and complicated zone of faulting that affected the Vaqueros and older formations. The downthrown side is on the northeast. Faulting along the same zone is the cause of the prominent scarp of Castle Mountain, farther west. Within the area mapped the movement took place probably before the beginning of Tertiary time, leaving the fault scarp as the shore line during the Tejon (Eocene) and Vaqueros (lower Miocene) epochs. The fault is not exposed east of Reef Ridge because covered by the later formations. The lowest of these, the Santa Margarita, is only very slightly wrinkled at this point, showing that practically all movement along this part of the Castle Mountain fault ceased before the upper Middle Miocene.

Pyramid Hills anticline.—The Castle Mountain fault zone is the locus of an important anticlinal fold that was formed during the Pleistocene long after the cessation of fault movement along the eastern portion of the zone. The Santa Margarita and younger formations have been worn off over the summit of the fold and the rocks exposed along this uncovered axis belong in part to the Knoxville-Chico, but some strange varieties differing from any observed elsewhere occur and have not been identified as belonging to any known formation. The disturbance of the pre-Santa Margarita rocks has been so great that the axis of the anticline is not easily traceable within the faulted zone. To the southeast the general zone of faulting gives place along a divergent axis to an overturned anticline in the Knoxville-Chico rocks, and this is traceable into a regular, sharp fold covered by the shale of the Santa Margarita. This is the anticline forming the prominent ridge of the Pyramid Hills and the northeastward-tilted monocline of Reef Ridge and the Kreyenhagen Hills.

Avenal syncline.—On its southwest flank the Pyramid Hills anticline dips down into the Avenal syncline, which determines the position of McLure Valley. North of Avenal Creek this syncline is an extremely sharp fold, overturned and much disturbed beyond the area mapped, but gradually plunging and becoming shallower toward McLure Valley.

Diablo anticline.—Southwest of the valley the beds rise again steeply on the flank of the Diablo anticline, which is a steep fold plunging rapidly toward the southeast and forming Avenal Ridge, the end of the Diablo Range. Its axis was once overarched by the Santa Margarita and later formations, but is now denuded of these formations and exposes greatly disturbed Knoxville-Chico rocks. This anticline is one of the main axial folds of the Diablo Range.

CHARACTER OF THE FOLDS AND FAULTS.

The structural features in this region are almost invariably plunging and curving. Most of them represent important and continuous structural lines along which movements of locally variable amount and direction have taken place. The anticlines are as a rule asymmetric elongated domes, the summits being broad and the dips increasingly steep away from the axis, but having varying limits of angle on the two sides and at different points along the longitudinal extent of the fold. The synclines have a reciprocal character. Several of the anticlines, notably the Coalinga, Jacalitos, and Pyramid Hills anticlines, are so formed that an axis may be traced on one or the other flank along which is a marked steepening of the dip away from the summit of the fold. This indicates an inclined position for the main axis of the fold. An overturn occurs in the inclined axis of the Coalinga anticline at one point along Oil Canyon, and overturns occur likewise along the Pyramid Hills anticline, the Avenal syncline, and on the northeastern flank of the Diablo anticline. An important feature of the structure of the district is that the northern portion of the axis of the Coalinga anticline and the axis of the Jacalitos anticline lean toward each other, the former toward the southwest and the latter toward the northeast, as if due to a compressional force from the two sides toward the Coalinga syncline. The Pyramid Hills anticline is analogous in this respect to the Coalinga anticline northeast of Pleasant Valley, and seems to be opposed in a similar way across McLure Valley by a contrary thrust in the Diablo anticline. The two latter folds have, however, not been studied in detail.

In regard to the character of the faults in this region little can be said, owing to the fact that the areas of older rocks in which they chiefly occur were examined only in a reconnaissance way. In the case of the Los Gatos Creek and Castle Mountain fault zones the planes of movement have been many and the resultant downthrow in each case is on the northeast.

THE OIL.

OCCURRENCE.

The petroleum in the Coalinga district occurs in four different formations, the Tejon (Eocene), Vaqueros (lower Miocene), Santa Margarita (upper middle Miocene), and Jacalitos (upper Miocene). In the first the oil is thought to be primary—that is, it is believed to have originated in the formation; in all of the others it is secondary—that is, it has come into them from some outside source since their formation.

OIL ZONES.

Geologic position.—Within each of the formations are one or more oil-bearing zones, consisting either of more or less extensive layers of sand or gravel, which can be traced in a general way over large areas, or of local lenses of the same materials. The oil sands in the Tejon (Eocene) will be referred to collectively as the Tejon oil zone; those in the lower part of the Vaqueros as the lowest Vaqueros zone, or zone D; those in the middle Vaqueros (Eastside field light-oil sands) as the light-oil zone, or zone C; those in the upper Vaqueros (first sand) in the fields northeast of Los Gatos Creek and in the lower Jacalitos in the Westside field south of Los Gatos Creek as zone B;

and those in the Jacalitos in the Westside field above the productive basal beds of that formation as zone A. The top of zone B is shown in contour on Pl. II. With the exception of those in the lowest zone in the Vaqueros (zone D) the oil sands are known to consist in many places of more or less local beds or lenses showing abrupt differences in thickness, composition, grain, and hardness from well to well, often with a puzzling diversity in gravity of product within short distances. Zone D, as would be expected of the basal portion of a widely spread formation, partakes of the same general characteristics throughout nearly its entire range within the district—that is, it is usually coarse gravel at the base, with somewhat finer gravel or very coarse sand above this, and finally medium-grained sand. The productive beds in the other zones vary from medium fine-grained to coarse pebbly sand or even gravel.

Tejon oil zone.—The sandstones underlying the shale of the Tejon (Eocene) formation or interbedded with its basal members contain commercial quantities of oil on the Coalinga anticline in the Oil City field, and also at several points on the flanks of the great steep-dipping monocline in the Kreyenhagen field. Many oil seepages occur along the outcrops of these sands, and it was the inducement offered by these seepages in the Oil City region that led to the drilling of the test wells from which the present district has been developed. The oil in the Tejon is usually of light gravity, about 33° to 34° B., and greenish in color. The thickness of the productive sands is ordinarily between 15 and 60 feet, and the yields are light, 4 to 75 barrels per well per day being the normal extremes of production, although the initial flow of one of the Oil City wells is said to have been 700 barrels per day.

Vaqueros oil zones.—The principal oil-bearing formation in the Coalinga district is the Vaqueros or lower Miocene. It yields practically all of the oil in the Eastside field, a considerable part of that from the Westside field, and is thought to contain commercially important quantities in the Kreyenhagen field and in the region of the Kettleman Hills. The total distance penetrated through this formation by the wells in the Eastside field is about 700 feet, and in the Westside between 300 and 500 feet. The actual productive sands of course occupy only a relatively small space in this column, usually less than 150 feet in the Eastside and less than 100 feet in the Westside. Three zones are recognized in this formation, the lowest, or zone D, the middle, or zone C (productive only in certain parts of the Eastside field, where it yields oil up to 31° B. in gravity), and zone B, recognized as Vaqueros, in the Eastside field and in the northern part of the Westside field. The oil from the Vaqueros varies in gravity from 14° to 22° in the Westside and from 14° to 31° in the Eastside. It is black or dark brown and the production averages between 100 and 200 barrels per well per day. One well in the Eastside field is now flowing 3,000 barrels of oil per day, and an initial yield of 7,000 barrels in eighteen hours was recorded for another well in the same field, but these figures are unusual.

Santa Margarita oil zone.—A stratum of sand carrying characteristic fossils of the Santa Margarita formation immediately overlies the Tejon in the region of the San Joaquin coal mine in the Westside field, but is so closely associated with lithologically similar beds of the Jacalitos in the same vicinity that it has been mapped and discussed with them as zone B. The persistent stratum of fine blue sandy shale found throughout the Eastside field and known locally as the "Big Blue," is arbitrarily placed in the Santa Margarita formation. The "Big Blue" immediately overlies the uppermost Vaqueros oil zone, zone B, the top of which is shown in contour on the map (Pl. II).

Jacalitos oil zones (*A and B*).—The Jacalitos (upper Miocene) formation is productive throughout the Westside field, except at the extreme southern and northern ends and in those wells distant over a mile or so from the outcrop of the sands. In other words, the formation is commercially oil bearing wherever it rests upon or is relatively near to the Tejon formation, the source of the oil.

Two oil zones are recognized in the Jacalitos, the lower, or zone B, which is the productive zone over the southwestern part of the Westside field, and zone A, situated some 200 feet above zone B, which carries tar sands or poorly saturated oil sands. The two zones are generally separated by sulphur water—the "big sulphur"—although the most persistent sulphur water in the northern end of the Westside field overlies zone A. Northward in the Westside field the productive sands of zone B are found lower and lower in the series of beds until in the northern end the oil is believed to come from beds in the uppermost Vaqueros, just below the base of the upper Miocene (either Santa Margarita or Jacalitos).

ACCUMULATION OF THE OIL.

The influence of structure on the accumulation of the petroleum varies somewhat for different parts of the field, the variation being due, it is believed, to the presence or absence of water beneath the oil zones in the various areas. In general the oil in the Tejon (Eocene) is accompanied by water in the underlying beds, and possibly also in the oil sands far down on the dip; under these circumstances the anticlinal theory[a] of accumulation seems to hold good. A modified

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[a] The anticlinal theory of oil accumulation assumes that the oil, being of less specific gravity, rises above the water present in porous rocks and collects at the highest possible points in upward folds, being there confined by impervious strata arching over the folds. The presence of water, according to this theory, is considered as fundamentally necessary for the carrying out of the process of accumulation in anticlines. For a fuller discussion of this subject see Arnold, R., and Anderson, R., Geology and oil resources of the Santa Maria oil district, Santa Barbara County, Cal.: Bull. U. S. Geol. Survey No. 322, 1907, pp. 71 et seq.

form of the same theory is apparently applicable to certain monoclines, in which water is associated with oil, such as those in the Westside and Kreyenhagen fields, where, instead of impervious beds overlying the porous sands, the residual tar or heavy hydrocarbons left upon evaporation of the lighter substances originally in the contained petroleum seal the outcrops and hinder or prevent the escape of the oil from below.

Where no water exists in or is associated with an oil zone, as, for instance, in the deeper portions of the Westside field and in by far the greater part of the Eastside field, structure apparently plays but a minor part in the accumulation of the oil, the presence or absence of the petroleum in the porous strata of the zone apparently depending entirely upon the presence or absence of the oil-yielding shales of the Tejon (Eocene) below or near to the beds in question. If the Tejon is present under any particular sand or zone, then the abundance or scarcity of the oil depends largely on (1) the proximity of the particular sand to the Tejon; (2) the state of disturbance of the underlying shale of the Tejon, or its relative position (whether unconformable or conformable) to the overlying beds; (3) the degree of porosity and grain of the sands of the zone; and (4) the effectiveness of the barriers hindering the escape of the hydrocarbons (oil and gas) from the oil sands.

Within the tested territory of the Coalinga district it has been found that the areas of Miocene sediments (either Vaqueros, Santa Margarita, or Jacalitos), immediately underlain by the shales of the Tejon, are oil bearing; that the productiveness of these beds varies roughly inversely with their distance from the Tejon; and that the productiveness is greatest where the Tejon occupies a position of angular unconformity with the Miocene sands or is more or less disturbed, as near the axis of an anticline such as the Coalinga anticline.

GRAVITY OF THE OIL.

The gravity of the petroleum at any point in any particular bed is apparently influenced chiefly by (1) the original composition of the oil; (2) the thickness and composition of the media through which it has migrated and in which it is detained; (3) its present or past association with water; and (4) its present distance from the outcrop of the oil-bearing zone or its depth below the surface, etc. Little definite information is now available concerning the effect of many of these factors. It seems in general, however, that the oil loses in gravity by migration either upward through various strata or along a particular bed; that it loses on association with water; that within certain limits it decreases in gravity up the dip, owing, probably, to proximity to the surface, with its accompanying facilities for the escape of certain of the hydrocarbons; and that, other things being equal, the finer the grain of the containing reservoir the better the oil will retain its original quality.

RELATIONS OF WATER TO OIL.

The most important problem next to that of the actual occurrence of the petroleum in any field is the relation of the water sands to the sands containing the oil. One or more sands carrying water are almost invariably encountered above the Miocene oil zones in the wells of the Coalinga district. The continuity of these sands can seldom be traced far, and they are believed to be for the most part disconnected lenses rather than far-reaching beds. An examination of the surface outcrops leads to the same conclusion. The contents of these upper water sands is believed to be surface or secondary water—that is, water which has percolated into them since they were tilted into their present position and their edges exposed. This secondary water is seldom under much head, although in a few instances it has been known to flow with considerable energy.

One of the most persistent layers or zones of water is the one termed the "Big Sulphur," a malodorous blackish fluid met with in or above zone A in the Westside field north of Los Gatos Creek, and between zones A and B south of Los Gatos Creek. No productive oil sands are found above this sulphur-water sand, although one or more tar sands are sometimes found; it may therefore be considered the limit of the upward migration of the oil, at least in commercial quantities. A similar and fully as persistent zone of sulphur water is encountered immediately above the second oil zone, zone C, over a large part of the Eastside field. The sulphur content of these waters probably bears an intimate relation to the oil, for in all of the seepages in this field where the oil is accompanied by water the latter is heavily charged with sulphur. However, not all of the sulphur springs in the region contain oil, so that there is a possibility of the sulphur even in this particular sand having an origin independent of the petroleum.

In all of the wells in the Westside field in which the Jacalitos or upper Miocene oil zone (zone B) can be recognized the latter is immediately underlain by a stratum of water. For various reasons it is thought that in this case also the water is secondary and has come into the formation since the passage of the oil from the Tejon (Eocene) into the Miocene. With the exception of a very limited area in the Eastside field no water has so far been reported from below the lowest Vaqueros oil zone (zone D), which indicates almost conclusively that water was not the elevating force for the oil of zone D; it also strengthens the conclusion that the water in the higher zones is surface water that has percolated from the outcrops in the local catchment basin, rather than primary water, that has been in the beds since their deposition, or water that has come up from below under hydrostatic pressure.

ORIGIN OF THE OIL.

As to the origin of the oil in the Coalinga district, it can be stated unequivocally that it comes from the shales of the Tejon (Eocene) formation; and it is believed that it is derived from the organic material in them. These shales are composed largely of the tests or shells of diatoms and Foraminifera, and a smaller number of other organisms, in such abundance as to fully warrant the assumption that the animal and vegetable material that must have been contained in them when deposited was adequate for furnishing a quantity of hydrocarbons and other compounds more than equivalent to the quantity of petroleum found in this field. The shales of the Tejon are everywhere petroliferous, their interbedded sands productively so, and wherever overlain by sediments these also are petroliferous. Furthermore, the relative productivity of these overlying beds varies inversely with their distance from the Tejon. If the shales of the Tejon were simply the medium of migration for the oil from below, the shales of the subjacent Knoxville-Chico (Cretaceous) would also be expected to serve as such, for they are lower down stratigraphically and are apparently of proper consistency (clayey shale) for migration by diffusion. We would also expect to find them charged with oil, their interbedded sandstones productive, and the Miocene overlying them containing at least as much, if not more, oil than the same formations overlying the Tejon. But these postulated conditions concerning the Knoxville-Chico (Cretaceous) do not exist. The Cretaceous shales and sands have been examined carefully in outcrop, and wells have been drilled into them in several places, but practically no indications of petroleum were found. The Miocene (Vaqueros, Jacalitos, and Etchegoin) sands overlying the Cretaceous in a position analogous to that of the Miocene overlying the Tejon (Eocene) yield oil only when situated comparatively near the Cretaceous-Eocene contact. This is most significant, indicating that the Cretaceous did not yield the oil, but that the latter, as would be expected, after passing from the Eocene into the Miocene has migrated for a short distance along the strata of the latter out over Cretaceous beds. Other negative evidence pointing to the origin of the oil in the Tejon is presented by the fact that there are no faults of consequence within the productive area along which migrations from depths could have taken place.

THE OIL FIELDS.

SUBDIVISIONS.

For convenience of discussion the Coalinga district has been roughly divided into five fields or regions, and these into lesser subdivisions or areas. The major subdivisions are as follows: (1) The Oil City field, lying in Oil Canyon near the north end of the district; (2) the Eastside field, embracing the territory northeast of Oil Canyon and including Anticline Ridge; (3) the Westside field, extending southeastward from Oil Canyon as far as Alcalde Canyon; (4) the Kreyenhagen field, which includes the Jacalitos and Kreyenhagen hills, Reef Ridge, and the territory southward to the Kings County–Kern County boundary; and (5) the region of the Kettleman Hills, extending from the Guijarral Hills southward to the gap separating the Kettleman from the Lost Hills.

CONTOUR MAP.

EXPLANATION.

The contour map of the Coalinga field (Pl. II) shows the structure, boundaries of the more important geologic formations, and certain culture, such as towns, section lines, and a few roads. The structure in the productive territory is indicated by contours showing the distance above (marked by a plus) or below (marked by a minus) sea level of the base of the "Big Blue" or top of zone B in the Eastside field and of the top of zone B in the Westside field. The contour interval is 100 feet. By means of this map the direction and amount of dip of the strata in the oil-bearing formation may be calculated for any point in the field, and the depth to the various productive sands or zones may be approximated for most parts of the territory.

USE OF THE MAP.

Suppose it is desired to find the probable depth below the surface of the first productive sand at the middle of the north line of SE. $\frac{1}{4}$ sec. 24, T. 20 S., R. 14 E. An examination of the map will show that this point lies approximately on the underground contour line marked "—500;" that is, the top of zone B is here about 500 feet below sea level. A close approximation of the elevation of the point may be had by looking up the elevation for the nearest derrick (see list, p. 128), which happens to be Claremont No. 4, elevation 792 feet, and calculating the difference in elevation, say 22 feet lower, either by the eye or with an aneroid barometer. The distance from the surface to the top of the oil zone mentioned would, therefore, be 500 feet plus the 770 feet, or approximately 1,270 feet. As zone B is the uppermost productive zone for this part of the field, the depth desired is 1,270 feet.

Again, suppose it is desired to find the depth to the main commercially productive zone at the center of sec. 5, T. 20 S., R. 15 E. Proceeding as before, it is found that the depth of the uppermost zone is about 1,460 feet below sea level and that the elevation of the point is about 950 feet above sea level, or that the top of the uppermost zone is about 2,410 feet below the surface. It will be found, however, by reading over the text referring to this part of the field that the most productive zone is zone D, which lies from 300 to 450 feet below the top of the upper productive zone (zone B) in this region. Therefore the distance to the top of the commercially productive zone will be 2,410 feet plus 300 to 450 feet, or between 2,710 and 2,860 feet.

Suppose it is desired to find the dip or pitch of the beds in the NW. ¼ sec. 23, T. 19 S., R. 15 E. An examination of the contours shows that the beds are pitching a little east of southeast (or striking a little north of northeast), and that the dip is about 850 feet for half a mile, or about 32.5 feet per hundred feet at right angles to the strike. The south and east components of this dip may be calculated by measuring in these directions instead of directly down the dip of the beds, which is always at right angles to the direction taken by the contours.

BASIS OF THE CONTOUR MAP.

The section lines and other culture are the result of instrument work by E. P. Davis, of the Geological Survey. The log of nearly every well in the field that was either finished or down any considerable distance on April 1, 1908, was used in the determination of the underground structure and the compilation of the data concerning the oil zones. All of the obtainable surface evidence of dip, strike, and occurrence of petroleum was also used in the preparation of this map. In those places where the surface and well-log evidence were at variance the latter was usually followed. In unsymmetrical features like the Coalinga anticline and Coalinga syncline the plane of the axis of the fold is not vertical, and, therefore, the anticline as indicated by the contours showing the underground position of certain zones will not lie directly under the trace of the same anticline or syncline on the surface.

DIFFICULTIES OF PREPARATION AND DEGREE OF ACCURACY.

After carefully plotting all of the logs on a uniform scale it was found that the greatest obstacle to overcome in the preparation of the contour map was the correlation of the strata from one well to another and from one part of the field to another. The difficulties of such correlations are doubtless familiar to anyone who has tried to work out the underground structure of any of the California fields. It must be said, however, that the structure in the Coalinga district is more regular and the conditions more favorable for a successful study and mapping of the underground geology than they are in any of the other California fields so far examined by the senior author, not excepting the Santa Maria field, which was studied in 1906 and of which an underground-contour map was prepared.[a] The effort has been made to delineate on the present map all of the details of structure consistent with the use of the well logs as confidential information, and to supplement these details by showing for the untested areas what seem to be most likely the conditions of underground structure. Within the untested areas the underground contours are of course only hypothetical and are shown by broken lines.

Regarding the degree of accuracy it may be stated that the exact elevations of practically all of the wells in the field were used in the preparation of the map. The well logs are assumed to be accurate to the usual degree—that is, ordinarily to the length of one "screw," or about 5 feet. The factor of error for the developed territory is therefore small, but will necessarily increase with the distance away from the drilled ground. Future development will add much to the knowledge of this field, and will show the inaccuracies of the contouring as here presented, but it is hoped that the benefits which may accrue to the operators from a knowledge of the general structure of the field will compensate in a measure for the errors in detail which are to be expected in a map based on incomplete data.

DETAILS OF THE PRODUCTIVE AREAS.

OIL CITY FIELD.

LOCATION.

The Oil City field occupies the territory of the southern part of sec. 17 and the northern part of sec. 20, T. 19 S., R. 15 E. Conditions in the territory immediately south of Oil City in the southern part of sec. 20, which has been tested but found to be poorly productive, will also be discussed with the Oil City field. The Coalinga Oil Company and the Home Oil Company are the only producers now operating in the Oil City field.

GEOLOGY AND STRUCTURE.

The Oil City field is situated within the belt of shale and interbedded or underlying sands of the Tejon (Eocene) formation, the oil being obtained from the last-mentioned beds. The proved productive

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[a] Bull. U. S. Geol. Survey No. 322, Pl. X.

ground occupies the same general relation to the plunging Coalinga anticline as the productive territory farther southeast in sec. 28; it is on the more gently inclined or northeastern flank of the fold. Surface dips of 50° to 90° and even overturned dips occur throughout the area along the southwestern limb of the anticline, while a surface dip of 32° is the maximum for the northeastern limb. The well logs indicate a relatively constant dip of about 26° (42 to 44 feet per hundred feet) southeastward down the axis of the anticline and a relatively slightly steeper dip in the beds immediately north of it in the productive territory.

GEOLOGY OF THE WELLS.

The wells in the productive area all start in the brown shale of the Tejon (Eocene), and continue in brown, black, and blue shale to the bottoms except where they pass through the oil sand. From one to three sands are penetrated. The first is from 4 to 15 feet thick and yields the lightest oil, said to run as high as 40° B.; gas is also reported from the first sand in other wells, and in still others it is dry. The second and third sands comprise a zone 60 to 100 feet thick; in some of the wells this is petroliferous throughout almost its entire distance, while in others the two sands are separated, the upper usually running from 15 to 20 feet thick and the lower from 40 to 60 feet.

A section of the second and third sand in the productive area is as follows:

Section of second and third oil sands, Oil City area.

	Feet.
Hard sand	4
Soft pay sand	15
Very hard sand	6
Alternating hard and pay sands	47
	72

All of the sands are comparatively fine grained. The oil usually comes from the softer sands and the lower sand is generally the most productive, although it is entirely unproductive in some of the wells. The wells vary in depth from 300 feet to nearly 1,700 feet, and the productive zone is reached at depths varying from about 250 to 1,500 feet.

The southern part of sec. 20, T. 19 S., R. 15 E., has been rather thoroughly tested and, though most of the wells have yielded more or less oil, they were not deemed profitable enough to warrant continuous operation. The following log of a typical well in the abandoned territory shows the general character of the Tejon formation.

Log of Phoenix Oil Company's well No. 3, in SE. ¼ sec. 20, T. 19 S., R. 15 E.[a]

	Feet.
Pink shale	300
Sand with water	330
Dark-colored shale	420
Sand with sulphur water and oil	440
Dark-colored shale	500
White clay shale	520
Oil sand	535
Shale	540
White shale	560
Oil sand	575

This well is said to have yielded 50 to 60 barrels of black heavy oil (10° to 12° B.) for a short time. This low gravity is accounted for by the disturbed condition of the strata which the well penetrated, it being located directly on the anticline and just above an oil seepage in the canyon.

Well No. 2 of the Phoenix Oil Company, located about 300 feet west of No. 3, struck the sand at a less depth, but yielded less oil. No. 1 went to 1,300 feet, but being southwest of the anticline never produced. The above log and the conditions described are characteristic of most of the test wells put down in this area.

Following are descriptions of the wells that have been put down here south of Oil City:

Blue Goose Oil Company's well No. 1; E. ½ NE. ¼ sec. 20. Depth, 2,200 feet through brown and blue shale. No oil, but much water. Abandoned.

California Oil and Gas Company's well No. 1; SE. ¼ sec. 19. Formation, principally shale. Abandoned. Same company has well in SW. ¼ sec. 20, also abandoned.

Crescent Oil Company's well No. 1; SE. ¼ sec. 20. Depth, 900 feet. Little oil at 770 feet. Gravity, 11° B.

Mutual Oil Company's well No. 1; SE. ¼ sec. 20. Depth, 1,800 feet. Abandoned.

New York Oil Company's well No. 1; SW. ¼ sec. 20. Depth, 1,000 feet, all in brown shale. No oil. Abandoned. Well No. 2. Depth, 2,200 feet, in brown shale with few hard sand layers. No oil. Abandoned.

Selma Oil Company's well No. 1; SE. ¼ sec. 20. Depth, 1,742 feet. Little oil sand.

Zenith Oil Company's well No. 1; SE. ¼ sec. 20. Depth, 2,380 feet. A little oil sand at 1,735 feet yielding 10 barrels a day of amber-colored oil, 38° to 42° B. gravity. Later it was drilled deeper and struck a large quantity of salt water which rose to within 300 feet of the top of the hole. The oil sand in this well is probably the same as the uppermost sand in the productive Oil City area. The occurrence of salt water below this is suggestive of bottom or edge water for the Tejon (Eocene) lower oil sands. Well No. 2, same as Selma No. 1 (?).

PRODUCT.

The production of the wells in the Oil City area varies from the figure for the initial output of one well, said to have been 700 barrels of oil per day for a short time, to the daily run of certain others,

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[a] Watts, W. L., Oil and gas yielding formations of California: Bull. Cal. State Min. Bureau, No. 19, 1900, p. 140.

which now will average not more than 4 barrels a day. In several wells the oil is said to have flowed over the top of the derrick when the oil sand was first penetrated, as a result of gas pressure, which soon subsided. All of the wells have to be pumped after a short initial period of spontaneous flow. The average daily production at present is about 20 barrels per well. The average normal rate of decrease per well for the field, disregarding the rapid decrease from the initial production, has been between 15 and 20 per cent per year since 1900. The productiveness of the wells increases down the nose of the anticline toward the southeast, especially near the axis of the flexure. This is shown by the fact that well No. 3 of the Home Oil Company (the original Blue Goose well) and No. 7 of the Coalinga Oil Company have been among the best producers in the group.

The gravity of the oil varies from 48° Baumé, oil of which gravity occurs only in small amounts, being reported to come from the uppermost sand in some of the wells (5 gallons of 48° oil from one well, it is said), to the usual run, which tests between 33° and 34° Baumé. There is apparently little variation in gravity between the wells up or down the dip or along the strike. The oil is greenish to brownish in color and shows little viscosity.

EASTSIDE FIELD.

PEERLESS-CALIFORNIA DIAMOND-T. C. AREA.

LOCATION.

This area comprises that part of the Eastside field which includes the northeastern portion of sec. 21 and the northern part of secs. 22, 23, and 24, extending to the line between Tps. 18 and 19 south at the northern end of the district. The companies operating in this area are the Coalinga Peerless, Octave California Diamond, Lorene, T. C., Wm. Graham, Imperial, Bowling Green, and California Oilfields, Ltd.

GEOLOGY OF THE WELLS.

All of the wells in this area start down either in the Santa Margarita or Jacalitos formations (upper Miocene) between the top of the "Big Blue" and the base of the Etchegoin. They all reach, and some of them entirely penetrate, the Vaqueros (lower Miocene) formation, which includes the oil-bearing zones, B, C, and D, of this part of the field. The variation in the beds penetrated is quite rapid, as is indicated by the logs, and, with the exception of the "Big Blue," it is seldom possible to trace a single stratum for more than one-eighth or one-fourth mile.

The map (Pl. II) indicates by contours the distance of the base of the "Big Blue" above or below sea level. The "Big Blue" varies in thickness in the wells—if the distance penetrated be counted as equivalent to the thickness—from about 260 feet at the western edge of the area to over 350 feet in deeper wells toward the east. In fact, one of the deep wells disclosed a continuous shale formation for about 640 feet, but it is not believed that this entire thickness is included in the "Big Blue" farther west. One of the unique characteristics of the "Big Blue" for this area, and also for nearly the whole of the rest of the Eastside field, is the red-shale layers which are found at various points interbedded with the blue variety. The red shales are well shown in outcrop in secs. 3 and 10, T. 19 S., R. 15 E., where owing to their peculiar tints they may be seen for a distance of several miles. The red shale consists almost entirely of comminuted serpentine, which is naturally green but is turned red by the oxidation of the iron, of which serpentine contains a relatively high per cent. The red shale appears prominently on the sumps, where it forms brilliant coatings as the material is dumped from the bailers.

Water sands from 20 to 175 feet thick are found just above the "Big Blue" from the western part of the NW. ¼ sec. 22 eastward to the deepest wells. Lenses of water sand are also reported in the "Big Blue" from the middle of sec. 14 eastward.

Seashells are another characteristic of the logs of this part of the area. They occur from about 120 feet above the "Big Blue" in the Peerless area to 230 feet above it in the wells in sec. 12. Some of the deeper wells also show a layer of seashells about 530 feet above the "Big Blue."

A more or less persistent zone of sulphur sands occurs from 20 to 180 feet above the first productive zone, zone B, but is not reported in all the wells. Sulphur water also occurs below the productive sands in two of the wells only, while certain of the Peerless wells are said to yield no water whatever. These facts clearly indicate that the water occurs in more or less isolated lenses of sand, similar, in a general way, to the lenses carrying the oil.

Between the base of the "Big Blue" and the first productive oil sand (zone C) there is about 350 feet of dry sand, shells, and, just above the oil sand, some blue or brown clay or shale layers. These last are often interbedded with dry or poorly saturated oil sands (zone B, in part). The thickness of the strata intervening between the "Big Blue" and the top of zone C reaches 450 feet in the deeper wells farther east down the dip.

Very little regularity exists in the oil zones, as is shown by the well logs. The productive beds (zones C and D) consist of alternating coarse sands, fine gravels, blue and brown shale and shells, with coarse gravel at the base of zone D. The productive measures are usually about 225 feet thick, measuring from the top of the first productive sand to the brown Eocene shale of the Tejon formation, and though they comprise both zones C and D, a separation of the two is not possible in many of the wells. The total thickness in the wells from the base of the "Big Blue" to the brown shale of the Tejon is a little over 600 feet.

Various names have been applied to certain individual sands that have been traced for short distances throughout this area. Among these is the "Sauer Dough" sand, which is the uppermost sand in some of the wells along the western edge of sec. 22. It is usually about 10 feet thick. About 40 feet below the "Sauer Dough" is a 40-foot sand known as the "Pulaski." A careful comparison of the logs in the area shows that these two sands, and others also to which local names have been given, are not traceable for any great distance, although the names have been applied to various strata in wells over other parts of the Eastside field.

PRODUCT.

Nearly all of the wells in this area have been drilled since 1904, so that data concerning decrease in production are rather meager. The production of the wells varies from about 25 to something like 700 barrels, the production increasing down the dip, other things being equal. The T. C. well in sec. 22 is said to yield about 400 barrels a day, which is believed to be a fair initial average of what would be encountered over most of the area in properly handled wells 1,500 feet or more in depth. The average production for the wells in the area is about 125 barrels a day. The yield depends largely on the handling of the well, for holes going down under practically the same conditions give quite different results under various managements. One well which had an initial production of 200 barrels now yields only 20 to 25 barrels a day. This decrease is probably due not entirely to natural causes but to a sanding up of the hole. The gravity of the product from this area varies from 18° to 24° B. So many sands are perforated that it is usually impossible to tell the gravity of oil from any particular one. However, the uppermost important productive zone (top of zone C) in the area is believed to yield oil between 20° and 21° B. gravity. The next sand, say about 80 feet below the first, yields 24° B. gravity, or possibly slightly better, while the lowest sand (base of zone D), which rests directly on the shales of the Tejon, produces oil of 18° or 20° B. gravity.

Some of the wells yield a little water with the oil, and it is claimed by some drillers that this water comes from the oil sands, but it is the belief of the writers that in nearly every instance the water has leaked in from the surrounding water sands and is not obtained directly from the oil sands. Relatively little sand is yielded by the wells after the initial period of production, but much trouble has been encountered in some of the deeper wells owing to the gas pressure forcing the sand in from the bottom. Gas accompanies the oil in all of the wells and is also encountered alone in isolated pockets, many of which are above the productive zones. Other conditions being the same the greater gas pressure occurs in the deeper wells.

TECHNOLOGY.

The best success in shutting off the water in this area has been in landing the casing in a blue shale just below the sulphur-sand zone. Surface waters are shut off above this with a larger casing, but the purity of the oil depends entirely upon the careful handling of the lower waters immediately overlying the oil sands.

STANDARD-CARIBOU-CALIFORNIA MONARCH AREA.

LOCATION.

This area covers the northeastern portion of sec. 27, the southern part of secs. 22, 23, and 24, all of secs. 25 and 26, and the northern part of secs. 35 and 36. The following companies operate in this area: California Oilfields (Ltd.), the Standard, Caribou, Associated, Twenty-Two, Record, Pittsburg, and Boston & California.

GEOLOGY OF THE WELLS.

The wells in this area, as in the area farther north, start down in the Santa Margarita and Jacalitos (upper Miocene) sands and shales between the top of the "Big Blue" and the basal Etchegoin. In the area where secs. 21, 22, 27, and 28 meet, the "Big Blue" is about 220 feet thick in the wells, increasing toward the eastern limit of the productive territory to about 320 feet. Red shales are reported interbedded in the "Big Blue" in nearly all of the wells throughout the area, apparently thickening and becoming relatively more prominent in the deeper wells toward the east and north. Some white and light-blue shale layers also occur in the same zone, and in the western part of the area gray and brown dry sands are encountered above it. From a point a short distance west of the middle of the line separating secs. 22 and 27 the same sands contain water at various distances above the shale.

All of the strata from the base of the "Big Blue" to the top of the Tejon (Eocene), embracing a distance in the wells of from 620 feet to over 800 feet, are more or less petroliferous throughout this area. Three oil zones may be defined within these limits. The first zone (zone B, the top of which is shown on Pl. II) begins immediately at the base of the "Big Blue" and is from 100 to 180 feet thick, the greater thickness occurring in the deeper wells. In the western part of the area zone B consists of dry sands, dry oil sands, or poorly saturated oil or tar sands; farther east it is commercially productive in some of the deeper wells but not in all. Where productive, as in the western part of sec. 26, the gravity of the oil in zone B is about 14° to 16°. Below zone B and between it and zone C the strata are largely shale and dry sand.

The second and third zones (zones C and D) are closely related, the second being the uppermost important producer over most of the area. Zone C consists of medium-grained sand yielding light-gravity oil (24° B., or better), is about 100 feet thick, and begins about 400 to 480 feet below the base of the "Big Blue" There are usually from 1 to 4 productive sands in this zone. The lowest productive zone (zone D) rests directly on the shales of the Tejon (Eocene), is very coarse, consisting of pebbly sand or fine gravel, and is usually the best producer as regards quantity, although the oil is of but 20° to 23° B. gravity.

Sulphur water overlies zone B in the area north of a line drawn south of Caribou Nos. 11 and 10. Fossil shells are reported at the base of the "Big Blue" in some of the wells, while in others, as in the region farther north, they occur about 450 feet above the base of the "Big Blue." The sea shells in some of the Caribou wells are found just above the oil sand and associated with it.

PRODUCT.

Most of the wells in this area also have been begun since 1904, so that figures for decrease in production are meager. All of the productive sands in many of the wells are perforated so that it is often impossible to tell the production or gravity of any one sand. However, the general features of variation are known and will be indicated. The variation in the initial production in the wells is from about 150 to 1,600 barrels a day, and the average production at present is about 400 barrels. The best producers, as a rule, are among the deeper wells, although for one which is well up on the dip (SE. ¼ sec. 21) an initial yield of 1,500 to 1,600 barrels a day is reported. This well obtained 200 barrels a day from the upper sands, but was lowered into the deeper sands, where it made its phenomenal record. Besides the one mentioned there are at least two other wells in the area that have produced more than 1,000 barrels a day. The average decrease in production for three years has varied from about 20 to 40 per cent, but some wells are said to have held out much better than this.

The gravity of the oil in this area varies from 16° to about 24° Baumé. The heavy oil comes from the upper sands (zone B), which are usually more productive in the deeper wells. A well in the W. ½ sec. 26 is said to have yielded 600 barrels of 15° or 16° oil from zone B when first drilled. The middle zone (zone C) produces oil of about

24°, while the lower, coarser, but generally more productive sands (zone D) yield oil of 21° to 22° B.

Gas occurs in practically all of the wells. In some of them there is sulphur, but most of them yield a good quality free from this element. The influence of one well on the pressure in another is often very marked. A certain well, for instance, dropped off more than 25 per cent in production when another well within 300 feet of it was brought in.

STANDARD-CALIFORNIA OILFIELDS (SEC. 27) AREA.

LOCATION.

This area includes the eastern part of sec. 28 and the western part of sec. 27 excluding the portion along the southern line of sec. 27. The Standard and the California Oilfields, Ltd., are the only companies operating in this area.

GEOLOGY OF THE WELLS.

All of the wells start down in the Santa Margarita (upper middle Miocene) and Jacalitos (upper Miocene) formations (above the top of the "Big Blue" and below the base of the Etchegoin), which usually include alternating sands and shales with occasional water sands. These water sands as a general rule are in the form of lenses and can seldom be traced in the wells for more than an eighth of a mile.

The "Big Blue" maintains a pretty uniform thickness of about 250 to 300 feet throughout practically the whole of this territory. In the wells along the middle of the line between secs. 27 and 28, there is a fairly persistent stratum of water sand immediately overlying the "Big Blue." There are other water sands above this lowest one in some of the wells, but none that can be traced far. An interesting stratum encountered in the wells beginning in the vicinity of the California Oilfields, sec. 27, No. 20, and extending down into the northern part of sec. 34, is known as the "St. Paul sand." It lies about 830 feet above the base of the "Big Blue," or from about 150 to 600 feet below the surface. It is about 30 feet thick and is hard, but is believed by some of the operators to be capable of yielding commercial quantities of oil, though, so far as known, it has never been thoroughly tested. This occurrence is rather puzzling, as there are no other oil sands within several hundred feet of it, and the origin of its petroleum is difficult to explain.

The oil-bearing formation in the area under discussion extends from the base of the "Big Blue" for about 655 feet, as measured in the wells, down to the top of the brown shale of the Tejon (Eocene). This distance between the base of the "Big Blue" and the brown shale is apparently regular over that part of the area which has been tested.

The wells in the deep territory have not penetrated the entire thickness of the oil sands, so that the exact thickness of the sands is not known for wells far down on the dip.

Three zones are recognizable in this series of productive beds. The first (zone B) occurs at the base of the "Big Blue," is about 15 to 20 feet thick, and yields from 30 to 50 barrels of 21° oil in the shallower wells.

The second (zone C) is about 300 feet below the top of the "Big Blue," has a thickness of 60 feet, and produces daily from 100 to over 1,000 barrels of 22° to 24° oil per well. A group of wells in the middle of the western part of sec. 27 and in the eastern part of sec. 28 produce oil of from 25° to 31° B., the initial production of the wells varying from 125 to 1,900 barrels per day. The oil from zone C, in this local area of unusually light oil, is kept separate in most of the wells, but whether or not all of the yield from the big producers in this light-oil area comes from zone C is not known. The sands in this light-oil zone are finer grained than those in the zone above or the zone below.

The third oil zone (zone D) consists of coarse, pebbly sands and fine gravels, and extends practically from the top of the brown shale of the Tejon upward for over 100 feet. Oil-bearing sands are found at practically all horizons in one well or another from the base of zone C to the top of zone D, so that a separation of the two is necessarily more or less arbitrary.

PRODUCT.

The wells in this area have all been drilled since 1902. The product of those wells deriving their supply from the upper sands (zone B) varies from 30 to 50 barrels a day of 21° B. oil. The middle zone (zone C) yields from 125 to 1,900 barrels per well a day, the gravity ranging from 24° to 31° B. One well which had an initial production of 1,900 barrels a day in 1904 dropped to 1,300 barrels a day after one and one-half years. Several of the wells yield on an average 300 to 400 barrels a day, while another group averages but 125 barrels of 26° B. oil. The third zone (zone D) yields oil of 22° to 23° B. It is the best producer, as far as quantity goes, in this part of the field. The better gravity and greater production in this particular area is believed to be due to the position of the wells adjacent to the axis of the anticline, where the Eocene shales (Tejon), from which the oil is derived, are much more fractured, and where, in consequence of this fracturing, the oil is permitted to migrate more easily and with less loss in quality into the overlying porous sands. The concentration of the oil within the Tejon, previous to its emigration, was also doubtless accentuated along the anticline by the action of the water which occurs associated with or immediately underlying the oil sands in the Tejon.

The presence of the light oil in the finer sediments is believed to be due to the fact that the lighter hydrocarbons can escape more easily from coarser reservoirs than from fine-grained ones, so that, when once charged with the oil, the finer-grained sands allow it to maintain its original quality more perfectly than a coarse sand would. As would be expected, the production under the same pressure is considerably less in finer sediments than it is in coarse sands, but the length of productivity is consequently greater in the former than in the latter.

CALIFORNIA OILFIELDS (SEC. 34)-COALINGA-MOHAWK AREA.

LOCATION.

This area comprises the whole of secs. 34 and 35, T. 19 S., R. 15 E., and secs. 1, 2, 3, 4, 11, and 12, T. 20 S., R. 15 E. The California Oilfields, Ltd., the Southern Pacific, W. K., Turner, Claremont, and Coalinga-Mohawk are the companies operating in this territory.

GEOLOGY OF THE WELLS.

As in the other areas described, the base of the "Big Blue" is the horizon shown by the contours on the map (Pl. II). The wells in the northern part of the area start down in the Jacalitos (upper Miocene) beds immediately underlying the base of the Etchegoin. Those south of the line marking the base of the Etchegoin start in the sands or clays of that formation. The "Big Blue" in the wells of this area varies from 250 feet in thickness in the northwestern portion to about 380 feet at the southwestern border. The peculiar red, green, and light-blue facies of the shale that are characteristic of the "Big Blue" in the deeper wells farther north are also found in the deep wells in portions of this area. In the northwestern portion water sands appear to be interbedded at the base of the "Big Blue," as are also some tar and dry oil sands, with occasional gas pockets. There are also other water sands in the deeper wells, an especially persistent zone occupying a position about 600 to 800 feet above the base of the "Big Blue" in the wells in the southern part of the area. Some of the water in this zone is said to contain appreciable amounts of sulphur.

The "St. Paul sand," described in the last area, also occurs in the northern part of this territory, where it is encountered in practically all of the wells, in none of which, so far as the writers are aware, has it ever been tested. Those wells which have been put down to the brown shale of the Tejon (Eocene) indicate that the formation between the base of the "Big Blue" and this shale has practically the same thickness of 650 feet or thereabouts that it has in the region to the north. The whole of this distance is occupied by alternating sandstones and shales, which are more or less productive in the various wells. The relations existing between the various oil sands in this area are not well known, but it is believed that the sequence of zones, including B, C, and D, is similar to that in the area last described. A 10-foot oil sand carrying 17° B. oil occurs at the base of the "Big Blue," probably corresponding to the one which yields a 16° B. or heavier oil in sec. 26, and which has been correlated with zone B. One hundred feet below the "Big Blue" the second sand, possibly zone C, is penetrated, this being productive through about 20 to 25 feet. About 400 feet still farther down is the third zone (zone D), which is believed to rest upon the Eocene shale (Tejon). A thin layer of sulphur water is reported in some of the wells just above this third zone, but enough blue or brown shale intervenes to allow complete shutting off of the water before reaching the productive zone.

PRODUCT.

The wells in this area are only two or three years old, but since their inception they have maintained a reputation as the biggest producers in the field. The oil in these wells is usually accompanied by large quantities of gas under strong pressure. As an instance of their unusual productiveness, it is said that one well in the northern part of sec. 34 yielded about 7,000 barrels of oil in eighteen hours. In ejecting this large amount of fluid from the hole the casing was practically all torn out. This well is now producing but 150 barrels a day, which indicates that the great production was due to the extremely high gas pressure. Another well near the center of the southern part of sec. 27 is said to have yielded 4,500 barrels of oil a day for some little time. This well is now believed to yield about 3,000 barrels a day. The gravity of the oil from these big producers is between 23° and 24° B.

Another well in the northern part of sec. 34 yielded on an average about 1,000 barrels a day for over ten months. Still others of these wells ran from 600 to 800 barrels a day. One well, which yielded 26° B. oil as long as it flowed, now yields a mixture of 23° B. oil when it is pumped. This implies that the lighter oil is probably under the greater gas pressure, and when this pressure is removed, the heavy oil either forces back the lighter fluid or allows only a small percentage of it to enter the well. The lower zones (zones C and D) in one well are said to yield a stratum of 29° B. oil at the top, 22° B. in the middle, and 26° at the base, with an average of about 28°.

STANDARD-STOCKHOLDERS-HANFORD AREA.

LOCATION.

This area comprises all of sec. 28, except the extreme eastern edge, which is described in a previous section (p. 84). The Standard, Hanford, and Stockholders oil companies are the only operators.

GEOLOGY OF THE WELLS.

The "Big Blue" in this territory varies from about 200 to 230 feet thick in the wells. A layer of water sand is found just above it in the eastern part of the area, and in one or two instances lenses of water sand have been reported as occurring in the "Big Blue" itself. The oil strata extend intermittently from the base of the "Big Blue" for about 655 feet to the brown shale of the Tejon (Eocene). The first 400 feet of the productive measures consists of alternating gas sands, oil sands, dry sands, and tar sands interbedded with shales and clays, and has been correlated with zone B, although it is believed to comprise not only the zone B of the areas toward the east, but the strata to the top of zone C. In the northwestern part of the area this upper zone is more or less productive, some of the wells which produced from it alone yielding from 10 to 30 barrels per day of 20° B. oil.

One or two persistent layers of water sand occur from 50 to 100 feet above the base of zone B, or above the top of the second or light-oil zone (zone C). Enough blue or brown shale intervenes between this water sand and the productive beds below to permit shutting it off. Big oyster shells are reported in some of the wells just above the second zone, these probably coming from the same layer as that yielding the oysters in the Vaqueros formation on Laval grade. Zone C consists largely of fine sand from 20 to 60 feet thick and yields oil of about 21° to 22° B. gravity. The third zone, or zone B, consists of coarse sand to gravel and begins about 100 feet above the brown shale of the Tejon (Eocene). It is productive throughout its entire depth, and yields more than any other of the zones in this group of wells. The daily production varies from 40 to 300 barrels per well of 18° to 22° B. oil.

Toward the axis of the anticline which bounds the present developed territory on the southwest the strata are more or less irregular, on account of the steep dips which are developed by this profound fold. The logs of the wells along the axis are quite irregular and indicate variable conditions in both the dip and the productiveness of the beds. Water is also more troublesome in these wells, owing, it is believed, to the disturbed conditions of the elsewhere impervious beds that surround the water sands. There is very little gas in the sands toward the western edge of this area.

PRODUCT.

The wells in the area under discussion are the oldest in the Coalinga district except those in the Oil City area, and many of them have produced continuously since their inception. The first zone (zone B) yields up to 30 barrels per day of 20° to 22° B. oil; the second (zone C) yields a somewhat lighter oil, from 21° to possibly 23° B. and the third (zone D) produces as high as 300 barrels of 18° to 22° oil. Some of the wells yield sand from the lower productive beds and water is also mixed with the oil in some of the wells in the broken formation near the axis of the anticline. In none of the wells in this area is the water believed to come from the bottom of the oil zone.

WESTSIDE FIELD.

CALL-CONFIDENCE AREA.

LOCATION.

This area is located in the southwest corner of T. 19 S., R. 15 E., and comprises the territory controlled by the following companies: The California Oilfields, Ltd., the Call, Keystone, Ajax, American Petroleum, Ætna Petroleum, Commercial Petroleum, California Diamond, Main State (formerly the Guthrey), California Monarch, Confidence, and Kern Trading and Oil. The wells are located on the southeastward-dipping monocline of the Westside field at a point where the strike of the beds begins to bend from northeastward to eastward around the axis of the Coalinga syncline.

GEOLOGY OF THE WELLS.

All of the wells start down in the soft shales, sandstones, or gravels of the basal Etchegoin or in the upper Miocene beds immediately underlying this. Toward the western part of the area the wells apparently penetrate only through the upper Miocene formations. On the western side, that is, in the deeper wells of the Call, California Oilfields, Ltd., and Commercial Petroleum, the wells apparently reach sands in the lower Miocene (zone D) that are lacking or have not been reached in the wells in the western part of the area.

Zone B, the depth of which below the surface is indicated by contours on the map (Pl. II, in pocket), will first be described. Toward the western part of the area it contains the productive sands and is found from about 650 to 1,050 feet below the surface. The oil in this zone is apparently under considerable gas pressure, for in nearly all of the wells, even the shallower ones, the oil rises a considerable distance in the casing when the sand is first penetrated. The sand in the shallower wells varies from 10 to 20 feet in thickness, thickening toward the northeast from the region of the Kern Trading and Oil territory. The sand is medium grained to coarse and soft, and the wells producing from it yield large quantities of sand with the oil, especially at first. Some of the shallower wells have been known to flow when first brought in. Farther east, in the vicinity of the eastern Confidence wells and those of the Main State or Guthrey leases, the zone is apparently irregular and some of the logs of the wells, although reporting a production from the horizon at which the sands are found farther up on the dip, do not mention the thickness of the sands within the zone. Guthrey No. 1, which was the biggest gusher of this part of the field, might be mentioned as an illustration of the irregularity. The behavior of this well was quite unusual and the exact location of the sand producing the gas and oil which flowed so strongly at first is doubtful. Enough sand was ejected from this well to cover the derrick floor and the surrounding ground over 6 feet deep.

In the deeper wells zone B is apparently represented by two sands which are separated in some instances by a waxy clay. The total thickness of the sand in these wells runs as high as 50 feet. Still farther down the dip, or in the deepest wells in the area, zone B apparently becomes unproductive, although it yields evidences of gas and petroleum in small quantities. In one of the wells this zone was pumped for three weeks, but the operators concluded that there was water in it and abandoned their efforts.

About 200 to 300 feet above zone B is a zone of tar sands (zone A), which, as the name implies, are either dry or yield oil of heavy gravity. These sands vary in number and thickness from well to well, although the zone as a whole is fairly persistent over the entire area. Sulphur water occurs within zone A, usually at the base of the first tar sand, and at some of the wells it is found at two horizons within the zone. The thickness of the tar sand varies from a minimum of 10 feet in some of the moderately deep wells to nearly 100 feet or possibly more in those farthest up on the dip. Thicknesses approaching 100 feet are also occasionally met with in the deep-well area.

About 200 feet above the zone of the tar sands (zone A) is a very persistent stratum of water. This water is mineralized in all of the wells and in some shows traces of sulphur. Above this water zone are usually one or two other water sands, the first being only about 5 to 10 feet thick, but yielding considerable water. The second is of less importance and is apparently lacking in many of the wells.

In the deeper wells toward the eastern part of the area the most productive sands apparently lie below zone B and are believed to be in part the equivalents of the lower Miocene sands (zones C and D) which are the productive sands of the Eastside field. The exact relations of these zone D sands to the overlying ones are perplexing, but it is believed that zone D does not extend westward past the middle of the area under discussion, although to the knowledge of the writers no well has yet been put down which passes entirely through the strata overlying the Tejon (Eocene) in this part of the field. Some of the wells have reached what they call the black or brown shale, but it seems likely that these brown shales may be simply petroliferous shales intercalated in the sands of the Vaqueros (lower Miocene). This lower Miocene sand zone (zone D) lies from 100 to 300 feet below zone B. Productive lenses are found at two or three points throughout the zone, but no continuous oil sands have been definitely traced between the wells.

Taking the logs as a whole, they present the following features in passing downward from the surface. First, the incoherent soil and gravel, then a thick series of dry gravels, sands, and shale or clay, with occasional hard sandstone shells. The first water is encountered usually between 240 and 500 feet. From this downward two and sometimes three other waters are penetrated before reaching the tar sand zone (zone A). The zone of the lower water sand or sands is often marked by numerous hard sand shells. After passing through zone A, which varies from a few feet to over 300 feet in thickness, a 200-foot zone of blue shale is encountered. Below this occurs zone B which is characterized by medium-grained to pebbly sands, brown shales, and several well-defined shells. The shallower wells usually stop at the base of this zone, but the deeper ones penetrate some shale and sands from the bottom of zone B to the top of the third zone, which includes zones C and D and is usually characterized by hard shells and medium-grained sands.

PRODUCT.

The production of the wells in this area varies from an initial output of 20 to 50 barrels in the shallower wells to 3,000 or 4,000 barrels in some of the deeper ones, such as Guthrey No. 1, which was a pronounced gusher when first brought in. The daily average for these wells runs somewhere between 100 and 200 barrels, but some of them average as high as 300 to 350 barrels over long periods.

The gravity of the oil runs from 14° to nearly 20° B., the average for the shallower wells being about 16°, and for the deeper wells something like 18°. The best oil apparently comes from the middle zone (zone B), which is believed to correspond in a general way with the light-oil sands farther south in the Westside field.

MERCANTILE CRUDE-S. W. & B. AREA.

LOCATION.

This area comprises the southern part of the Kern Trading and Oil, Confidence, California Monarch, and E. W. Risley leases on sec. 31, T. 19 S., R. 15 E., the Fresno-San Francisco and the northern parts of the Cypress and Pennsylvania-Coalinga properties in the northeastern part of sec. 1, T. 20 S., R. 14 E., and the Mercantile Crude, York-Coalinga, S. W. & B., New San Francisco Crude, and the northern half of Esperanza in sec. 6, T. 20 S., R. 15 E. The wells are located on the southeast-sloping monocline which dominates the structure of the whole Westside field.

GEOLOGY OF THE WELLS.

The wells in this area all start down in the basal Etchegoin (upper Miocene) clays, sands, gravels, etc., and the Jacalitos (upper Miocene) beds immediately underlying these. Three more or less well-defined petroliferous zones are developed in this area. The top of the principal productive zone (zone B) is shown by contours on the map (Pl. II). In wells high up on the dip the sand in zone B is coarse, and it usually contains pebbles the size of the thumb or sometimes even larger. Both immediately above and below the most productive part of the zone are sands in which the oil is of heavier gravity than that in the most productive part. The reason for this variation in gravity between sands so close together is not at present known, but the variation may be due, in part at least, to variation in grain of the sands. Farther down the dip the sand becomes somewhat thicker, but is still quite coarse and in some of the wells is characterized by the presence of shark's teeth. The coarseness of the sand and the gas pressure are conducive to good productions, and it is not unusual for wells at first to obtain as high as 300 or 400 barrels a day from this one sand. In the deeper wells the zone apparently contains but one sand, which is in most cases underlain by a more or less persistent hard sandstone shell. The gravity of the oil in zone B runs about 17° B. and is apparently constant throughout the area. From 50 to 100 feet above zone B is a 100 to 200 foot zone (zone A) of tar sands similar to those encountered in the wells toward the north. This tar zone is thickest in the northwestern part of the area, where it consists of from one to three dry oil sands or tar sands, which sometimes contain heavy oil and occasionally water associated with the oil. Eastward, or down the dip, the tar sand decreases rapidly in thickness, until in the deepest wells in the area the tar zone is represented by but one or two sands which never attain more than 10 or 20 feet in thickness. Immediately overlying zone A is a persistent stratum of sulphur water, which is encountered in practically all of the wells in this area and is known in general under the name "big sulphur" or "main sulphur." Beneath this sulphur water in most of the wells is a hard sand shell, which is apparently more or less persistent throughout the area. Still another sulphur water is encountered a little above the lower one in some of the wells, but does not appear to be as persistent as the "main sulphur."

Below zone B in the deeper wells is still a third petroliferous zone (zone D), which may correspond in part to the lowest zone in the area immediately north. It is penetrated by but two or three wells and its productiveness is more or less uncertain. In one log this lower sand is mentioned as brown shale, although the same log shows that the casing was perforated at this point, thus indicating that the formation was oil bearing.

The water sands in the area are usually three or four in number, the uppermost being encountered at from 145 to about 375 feet in depth. The first sand is apparently not so productive as the second, which yields plenty of water in many of the wells. Below the second sand is a third and sometimes even a fourth, before the sulphur sand, immediately overlying the tar zone, is encountered.

Typical well log in Mercantile Crude–S. W. & B. area.

	Feet.
Surface soil and incoherent sand and gravel, followed by harder shales, sandstone, and gravels	200
First water sand	5- 20
Shale	50+
Second water sand.	
Shale, sometimes containing one or more water sands	300
Gravel, more or less persistent stratum, apparently carrying water in several of the wells, especially those nearest the outcrop.	
Shale	100
"Main sulphur" water	5- 20
Tar sand (zone A)	100-200
Shale	50-100
Productive sands (zone B)	20- 50
Shale, largely brown	50-200
Zone D	20- 50

The depths of the wells in this area vary from about 1,000 feet to over 1,700 feet.

PRODUCT.

The production varies from 12 barrels in the wells farthest west to about 400 barrels in the deeper and more productive ones. Large quantities of sand usually accompany the oil, especially in those wells high up on the dip, and even in some of those which penetrate the sand at much greater depth. The gravity of the oil varies from about 13° to 17½° B., the average for the area probably being about 16°.

ZIER-PORTER AND SCRIBNER-M. K. & T. AREA.

LOCATION.

This area comprises the southern part of sec. 1, T. 20 S., R. 14 E., the southern part of the Esperanza property, sec. 6, T. 20 S., R. 15 E., and the regions in sec. 12, T. 20 S., R. 14 E., and secs. 7 and 8, T. 20 S., R. 15 E. The companies operating in this area are the Zier, Ward, Seneca, Cypress, Pennsylvania-Coalinga, Esperanza, Shawmut, Section Seven, Coalinga Pacific, Porter and Scribner, Brix and Buntin (B. & B.), California and New York, and M. K. & T. The wells are located on the flanks of the southeast-dipping monocline which governs the structure in the Westside field.

GEOLOGY OF THE WELLS.

The wells start down in the basal Etchegoin or the immediately underlying soft beds of the Jacalitos formation. Zone B, the one shown in contour on the map (Pl. II), is at present the most important zone in this part of the field, and yields the greater part of the production. In the western part of the area it varies from alternating sands and shales to a single bed of coarse sand 25 feet thick. The gravity of the oil from the zone in this part of the area varies from 13° to 14° B. Farther east and lower down on the dip the gravity of the product from zone B is considerably higher, ranging from 17° to 18° B. The beds yielding this lighter oil may possibly not be continuous with those farther west which produce the oil of 14° B. gravity. On the contrary, the sands yielding the latter may possibly be represented in the eastern part of the area by the sands yielding 14° B. oil which immediately underlie the 17° B. oil sand. The 17° B. oil sand is not fine grained, but is fairly coarse and in many of the wells contains shark's teeth, as it does in the area farther north. The zone, as indicated by logs, varies in thickness from 7 to 60 feet in the central part of the area. The production from a single sand in this zone ranges from 40 or 50 barrels up to the daily maximum of about 200 barrels per well. The light-oil sand appears to be missing in some of the wells according to their logs, but it is believed that the formation is represented in the well, but was overlooked by the driller while the hole was full of water. In the deeper wells, toward the eastern end of the area, zone B maintains the characteristics just described, varying in thickness from 8 to 30 feet, apparently being mixed with some shale in the thicker portion.

As in the areas farther north, zone B thickens rapidly toward the east until in the region of sec. 8, T. 20 S., R. 15 E., indications of petroleum are found throughout a vertical distance of over 1,100 feet. Here zone B is believed to be represented by what is known as the third or light-oil sand of the M. K. & T. wells, which lies several hundred feet above the most productive sands in those holes, is medium grained, nearly 100 feet thick, and is said to yield oil of 22° B. If zone B is continuous, wells located between the Porter and Scribner and M. K. & T. leases ought to show a gradation in gravity from 17° to 18° B. in the former to the 22° B. oil in the latter, which is much farther down the dip. This decrease in specific gravity (increase in degrees Baumé) down the dip agrees with the mode of variation found in most instances in the other California fields examined by the writers.

The same tar-sand zone (zone A) is encountered above zone B in this area as is found in the same portion throughout most of the remainder of the Westside field. It varies in thickness from 20 or 30 feet to over 100 feet, being exceedingly irregular as reported in the well logs, although it is on the whole believed to be thicker down the dip toward the east. The tar sands are usually intercalated with shale and are often dry, but in some wells yield a small production of heavy oil of about 14° B. gravity or heavier. Prominent sandstone shells are usually associated with the sands and shales of this zone, some of these shells being traceable from well to well, and one in particular, of considerable importance, has been called the "Big Shell."

Below zone B and closely associated with it is a zone of 14° or 15° B. oil. This zone (zone D) has been penetrated in some of the wells for over 300 feet and found to consist of alternating sands and blue and brown shales, the brown shales usually predominating. It is barely possible that this lowest shale in the deepest wells is Tejon (Eocene), but no proof of this is available. Zone D is probably equivalent in part to the lower Miocene sand of the Lucile well and the wells in the Eastside field. In the deepest wells, which obtain most of their oil from zone D, the latter is always more productive than zone B.

Three or more water sands are usually encountered in the wells in this area. In the shallower wells and even in some of the deeper ones the water sand is met at depths of less than 200 feet. Below this first layer and separated from it by about 400 feet of shale is usually the second sand, but in some of the wells within this distance minor beds carrying water are encountered. Below the second main water sand and immediately overlying the tar zone (zone A) is a rather persistent stratum of sulphur water reported in most but not all of the wells. It is more commonly found in the deeper holes and may be represented in the wells toward the western part of the area and higher up on the dip by certain members of the tar-sand zone. If this be so, it is interesting as showing that the hydrocarbons in the tar sand have been forced upward by the sulphur water which fills up this particular porous stratum, presumably under hydrostatic pressure.

Typical well log in Zier-Porter and Scribner-M. K. & T. areas.

	Feet.
Surface clay and sand with a little gravel	200
Water sand	20- 40
Blue shale	350
Water sand or water gravel	40
Sulphur water sand (main sulphur)	30- 50
Blue shale or shells	10- 20
Alternating tar sands (zone A) and shale with 50 or more feet of shale and shell at the bottom	200
Productive 17° or 18° B. oil sand (zone B)	10- 60
Alternating oil sands and blue and brown shales, including zone D	300

PRODUCT.

The production of the individual wells in this area varies from 40 or 50 barrels to a maximum of about 300 barrels per day. The gravity of the oil in those wells in the western part of the area, well up on the dip, is about 12° to 14° B., while in the deeper wells, producing from the light-oil sand, an average of about 17° or 18° B. oil is obtained. The deepest well in the area, the M. K. & T., is said to yield oil of about 16½° B. This oil is believed to come from zone D, in the Vaqueros (lower Miocene) formation.

ASSOCIATED-CALEDONIAN-UNION AREA.

LOCATION.

The area described under this heading embraces the region from the Union lease in sec. 13, T. 20 S., R. 14 E., southward to the southern part of sec. 36 in the same township and range. It includes well No. 5 and all other Associated wells farther north in sec. 36; also the properties of the Kern Trading and Oil, Southern Pacific Railroad, Valley Slope, Cawder, Blue Diamond, Caledonian, Angelus, Ozark, Euclid, Marengo, Traders, Norse, Premier, Claremont, Wabash, Inca, St. Paul-Fresno, Coalinga Western, New Home, M. M. Kew, Sleep & Fitzgerald, Coalinga Banner, Coalinga Petroleum, Elgar Adams, and Union oil companies.

STRUCTURE.

The wells in this area are located on the east-dipping monocline of the Westside field, the southern part of the area being located near the point where the strike of the beds changes from south to east of south. Except for a local flexure, which is possibly the continuation of one of the lines of disturbance in the White Creek syncline, the general position of the beds is regular and they have an easterly dip of 11° to 22°. The beds apparently flatten out in passing east from the steeper hills in the western and southwestern parts of the area to the valley floor.

GEOLOGY OF THE WELLS.

The wells start down in the soft beds of the Etchegoin formation or of the immediately underlying Jacalitos formation. Zone B, shown in contour on the map (Pl. II), is the principal productive zone in this field, as in those farther north. In the northern part of the area the zone consists usually of a single medium to coarse grained sand, varying in thickness from 20 to 30 feet. This thickness is fairly uniform throughout the northern part of the area, except that portion well down on the dip, where the zone apparently thickens and is penetrated for nearly 40 feet in some of the wells. It also thickens locally toward the western edge of the area, 50 feet of productive sand being recorded in one of the shallower wells. It is believed, however, that in this well a part of the thickness is made up of intercalated shale.

Southward the sand apparently becomes less and less productive, the southernmost well so far drilled which is believed to obtain oil in commercial quantities from this zone being Associated No. 5. Here the productive sand is practically of the same thickness as the average farther north, but in the wells still farther south the productive sand pinches out or is practically dry. The gravity of the oil varies from 13° to 17° B., apparently being heavier toward the outcrop of the beds and lighter down the dip. A variation in gravity between 14° to 15° along the strike is also noticeable, the southernmost wells producing the lighter oil.

Although zone B is the first productive zone encountered in the wells, there is above it a tar sand called the "Big Gumbo," which is penetrated by nearly all the wells from the Union south to the line of Associated wells along the northern side of sec: 36. This gumbo sand, as the name implies, carries a heavy oil or tar, which has so far not been utilized in any of the wells. In the region of the Caledonian wells at the western edge of the developed territory and farther up on the dip there is still a higher oil sand, but this also is nonproductive.

Below zone B are three well-defined oil sands throughout the region from the Union wells southward as far at least as the north edge of sec. 36. The uppermost of these sands varies from 10 to 50 feet in thickness, while the second is usually somewhat thinner. Hard shells are often associated with these lower sands, but in many of the wells blue shale is apparently the only parting. In some instances the sands below zone B are divided into three or four minor layers which show little regularity in thickness between the different wells.

The gravity of the oil in the zone below zone B is usually about the same as that in zone B, but in the Caledonian and Angelus regions an oil sand carrying 17° B. petroleum is found immediately underlying zone B. It is barely possible that this may be the equivalent of the light-oil sand in the region of the Coalinga Pacific and other wells of that same area, but it is the opinion of the writers that there is no direct connection between beds carrying the light oil in this southern part and the beds carrying oil of the same gravity in the region north of Los Gatos Creek.

In the region of the Wabash and Inca properties the oil sands are apparently the most regular of the Westside field, but on each side of this particularly regular zone the variations in the sands is considerable from well to well, both along and across the strike of the beds.

A persistent stratum of sulphur water sand is encountered in most of the wells between the gumbo or tar sand and zone B. This sulphur sand varies in thickness from about 10 to 20 feet, although in one of the Wabash wells it has apparently split up into two sands separated by shale, each sand member being somewhat less than 10 feet in thickness. In certain wells of this area the sulphur sand contains traces of oil, especially in those wells along the north side of sec. 36 and in some of the Union wells.

The formations above the zone of the gumbo or tar sand usually contain two or more water sands. In most of the wells the first sand is encountered at depths under 200 feet, but between this sand and the gumbo the occurrence of water is irregular. In some of the wells water sand approximating 50 feet in thickness is encountered 200 feet below the first water sand, whereas in wells near by the second water sand may be only 10 feet thick and may be separated from the first sand by one or two other strata carrying water. The water from all of those sands is considerably mineralized and is not fit for domestic uses.

Typical well log in Associated-Caledonian-Union area.

	Feet.
Shale	150
Water sand	20–30
Shale with some dry sand or gravel	200
Water sand	20–50
Blue shale with some dry sands and occasionally some water sand	600
Tar zone, zone A	8–50
Blue shale	20–100
Sulphur-water sand	20
Blue shale with occasionally fine sand layers. (The water is generally shut off in the upper part of this shale zone. Such a proceeding is doubtless flooding the gumbo sand, but as this tar sand is not believed to be productive in any part of the field the flooding is doing no harm.)	100–200
Zone B and various oil sands of more or less importance, the whole being thinnest near the outcrop and thickening gradually down the dip	100–225

One of the Caledonian wells was drilled to a depth of over 2,300 feet, but from the depth of something over 700 feet it passed through the usually unproductive Eocene brown and blue shales (Tejon formation) yielding warm salt water of 110° F. near the bottom. Sulphur water was also encountered at about 1,600 feet in this well, and a little greenish oil of over 17° gravity was encountered near the 1,000-foot mark. The base of the productive measure in this area is believed to be marked by a persistent stratum of salt or brackish water, which is encountered in wells drilled into the underlying Tejon shales.

PRODUCT.

The product in the wells so far drilled in this area comes from zone B, the Jacalitos (upper Miocene) formation. The daily production of the individual wells varies from about 400 barrels in the deeper wells to 50 or 60 barrels in the shallower. Many of the wells flow at first, and some of the deeper ones continue to flow for two or three years, but most of the wells are pumped after the initial head of gas has blown off. Much sand accompanies the oil, especially in the shallower wells, running as high as 50 per cent at first in some of the wells. Large amounts of gas are produced by most of the wells. The gravity of the oil varies from 12° B. in the shallow wells, those up on the dip, to 17° for the deeper holes. Three sands are recognized in the productive zone, the upper one yielding the lightest oil.

AREA BETWEEN WALTHAM CREEK AND SAN JOAQUIN VALLEY COAL MINE.

LOCATION.

The area treated in the following paragraphs comprises the territory lying between the Cretaceous-Vaqueros (lower Miocene) contact (which extends northwestward from Alcalde) and the valley floor west of Coalinga, and between Waltham Creek and the reigon of the San Joaquin Valley coal mine in the NW. ¼ sec. 26, T. 20 S., R. 14 E. A portion of this region, however, that in which the wells of the Sunnyside and Westlake-Rommel oil companies are situated, is omitted and will be considered separately.

The oil companies operating within this region include the Mount Hamilton, Commercial Petroleum, West Coalinga, Coalinga Zenith, Summit, Z. L. Phelps, Blaine, Yellowstone, Coalinga Southern, Section Six, T. C., Lucile, Shreeve, St. Francis, Associated, Southern Pacific Railroad, and some others not yet prosecuting development work.

GEOLOGY.

The formations involved in the geology of this area comprise the Knoxville-Chico (Cretaceous, sandstone and shale), the Tejon (Eocene, sandstone and shale), a series of sandstones overlain by soft shale which are believed to be largely of Vaqueros (lower Miocene) age, the Jacalitos (early upper Miocene, sandstone, conglomerate, and shale), and the Etchegoin (late upper Miocene, sand and clay shale).

The Knoxville-Chico rocks (Cretaceous) consist of dark thin-bedded shale with some sandstone, the latter in places carrying the characteristic brown concretions. It outcrops west of the area under discussion and extends in a northwesterly direction into the hills south of Los Gatos Creek. In the main the Cretaceous beds are steeply tilted, forming a monocline with an approximate dip of 60° SE. They carry no oil in commercial quantities, but are believed to yield the water in the Henshaw and West Coalinga wells.

The Tejon (Eocene) formation consists largely of medium-grained sandstone with some intercalated shales at the base and a considerable thickness of shale at the top. It occupies a small area in the SW. ¼ sec. 26, T. 20 S., R. 14 E., just south of the San Joaquin Valley coal mine. With the exception of this small outcrop the Tejon in this area is entirely covered by the later beds, which overlap it from the east and south. The basal Tejon overlies the Cretaceous apparently conformably and dips northeastward at an angle of about 30° and is itself in turn overlain unconformably by the Miocene beds.

Unconformably overlying the Knoxville-Chico (Cretaceous) and the Tejon (Eocene) just described is a series of beds consisting of about 250 feet of sandstones and over 100 feet of soft dark-blue shale.

These beds are known to be Vaqueros at the base, but the age of the uppermost member, the shale, is unknown. The latter, however, may possibly be the equivalent of the "Big Blue" in the northern end of the Coalinga field, although in the area under discussion it has been mapped with the Vaqueros, and in the Eastside field it is included in the Santa Margarita. The basal sandstone of the Vaqueros formation may be traced from a short distance south of the San Joaquin Valley coal mine southward across the northwest corner of sec. 35, T. 20 S., R. 14 E., along the western edge of the same section, into the middle of the NW. ¼ sec. 2, T. 21 S., R. 14 E., thence southeasterly to the bottom of the canyon near the middle of the south line of the SE. ¼ sec. 2. Thence it passes westward below and north of the summit of the big ridge which extends several miles northwesterly from Alcalde. Near the San Joaquin Valley coal mine the Vaqueros overlies the Tejon (Eocene), but near the northwest corner of sec. 35 it crosses the contact between the Knoxville-Chico (Cretaceous) and the Tejon, and from there southwestward it overlies the Knoxville-Chico. The contact between the Knoxville-Chico and the Tejon is believed to extend southeasterly underneath the Vaqueros diagonally through sec. 35, T. 20 S., R. 14 E., and diagonally through sec. 1, T. 21 S., R. 14 E. Its course from the latter region is not definitely known, but can be surmised, as is stated elsewhere (p. 118). The tracing of this contact beneath the Vaqueros is important because of the fact that the oil is derived from the Eocene shale, and it is believed that wherever the Vaqueros or other formations overlie the Tejon they will be found more or less petroliferous, while in the areas where the same formations overlie the Knoxville-Chico they will be found barren or containing only such petroleum as has migrated along the strata from areas underlain by the Tejon. It is worthy of note in this connection that along practically the whole extent of the outcrop of the base of the Vaqueros from the San Joaquin Valley coal mine southward to the southern part of sec. 2, T. 21 S., R. 14 E., the basal beds are more or less petroliferous. The indications are so strong in certain places, notably in the SE. ¼ sec. 2, that tunnels have been run into the base of the Vaqueros sands with the expectation of obtaining petroleum in commercial quantities.

Westward from the southeastern part of sec. 2 the basal Vaqueros sands become less and less petroliferous until on the flanks of the ridge spoken of as extending northwestward from Alcalde the beds show no indications of petroleum.

The description of the geologic section exposed on the surface along a line extending from the middle of the southern line of sec. 2, T. 21 S., R. 14 E., in Anticline Canyon, to the top of Flag Hill (located in the SE. ¼ sec. 1, T. 21 S., R. 14 E., and shown as the triangulation station on the topographic map) and thence in a direct line to the Lucile well covers all the formations of the area under discussion; this section is based upon a detailed surface traverse and in a general way upon the well logs of secs. 6 and 36 to the northeast:

Geologic section from Anticline Canyon in S. ½ SE. ¼ sec. 2, T. 21 S., R. 14 E., to Lucile well (beginning with lower strata).

[Dip approximately 20° NE.]

Vaqueros (lower Miocene). Beds 1–4.

Bed 1. Much-discolored and rusty-yellowish sand and soft sandstone, highly charged with petroleum in the immediate vicinity of Anticline Canyon, and about 150 feet thick. Not yet pierced by any of the wells in the sec. 6 area, but is believed to be a rich oil-bearing sand throughout its entire thickness. Represents the basal part of zone D of the developed territory.

Bed 2. Largely gypsiferous sand, with a hard fossiliferous layer at base. The fossils, which occur abundantly in Anticline Canyon a short distance below the southern line of section 2, are believed to be from the same bed as the fossil "clam" shells thrown out in the sand from the bottom of Lucile well No. 1. About 150 feet thick; probably represents parts of zones C and D in the Eastside field.

Bed 3. Soft sand with pebbly layers and occasional hard, coarse, rusty, sandstone strata, which would be called "sandstone shell" if encountered in the wells. About 200 feet thick, and is also a part of zones C and D. Beds 2 and 3 apparently thin out slightly toward the valley, as the thickness disclosed by the well logs is somewhat less than that obtained by calculation from the surface outcrops.

Bed 4. Largely clay, about 250 feet thick, and may be the equivalent of the "Big Blue" in the Eastside field.

Jacalitos (early upper Miocene). Beds 5–11.

Bed 5. Largely pebbly sand overlain by thin-bedded sand and soft sandstone. Bed of fossils, largely *Zirphæa*, at top; believed to be the ones reported in both the Shreeve and Lucile logs. These are an important tie line, not only in this particular area, but also throughout the Coalinga district. Bed believed to be the same as that which rests upon or near the Tejon, west of that part of the Westside field lying north of the San Joaquin Valley coal mine, and believed to be of upper Miocene age. Zone B, in the wells of the south and central parts of the Westside field, is between 100 and 200 feet in thickness.

Bed 6. Above the fossil bed are some coarse gray sand layers. Well in the NE. ¼ SW. ¼ sec. 12, T. 21 S., R. 14 E., begins in this zone of sand.

Bed 7. Clay; apparently thickens somewhat toward the valley, especially between the Shreeve and Lucile wells.

Bed 8. Persistent layer of soft pebbly sandstone, recognized in both the Shreeve and Lucile well logs.

Bed 9. Ten-foot layer of clay.

Bed 10. Another pebbly sandstone layer, apparently not so persistent as bed 8.

Bed 11. Important and widespread soft blue clay.

Etchegoin (uppermost Miocene). Beds 12–17.

Bed 12. Brown sand at the base, 10 feet of hard sandstone, then a layer of sand, another layer of sandstone, and finally soft sandstone at the top.

Bed 13. Soft blue shale, 15 to 200 feet thick.

Etchegoin (uppermost Miocene). Beds 12–17—Continued.

Bed 14. Coarse brown to greenish pebbly sand at base, overlain by coarse brown sand, containing numerous large fossil sand dollars, *Echinarachnius gibbsi* Rémond. About 125 feet thick.

Bed 15. This is sand and soft sandstone, pebbly at the bottom, and contains numerous fossils. It is known as a fossil bed in the wells in some parts of the field and contains such species as *Pecten oweni* Arnold, *Glycymeris*, etc. It is the *Glycymeris* zone not far above the base of the Etchegoin formation.

Bed 16. This layer is of bluish clay, about 100 feet thick.

Bed 17. From the top of bed 17 down to the detritus-covered valley floor in the vicinity of Lucile well No. 1 the beds exposed are largely coarse sands with occasional pebbly layers. Toward the edge of the hills some of the beds contain cobbles of considerable size and fossils indicating the same horizon as the *Pecten coalingaensis* zone, frequently mentioned in the discussion of the geology as near the top of the Etchegoin. Usually spoken of by the drillers as surface formation, as they appear to be largely incoherent and of a heterogeneous character. Uppermost possibly represent part of the Paso Robles formation.

STRUCTURE.

The main structural feature is, of course, the great southeastward dipping monocline that extends from the top of Curry Mountain and Juniper Ridge to the middle of Pleasant Valley. There are, however, one or two local lines of disturbance within the area which are worthy of mention. The most important begins in the Knoxville-Chico rocks (Cretaceous) somewhere northwest of sec. 2, T. 21 S., R. 14 E., and passes southeastward apparently almost coincident with the bed of Anticline Canyon. From the south line of sec. 2 to the middle of the E. ½ SW. ¼ sec. 12 this line of disturbance has the character of a southeastward-plunging anticline. The dips on the east are apparently about 20°, while those toward the south vary from 8° or 10° in the region immediately south of sec. 2 to 30° or 40° in the southern part of the SW. ¼ sec. 12. At a point a short distance west of the east line of the SW. ¼ sec. 12 the line of disturbance bends abruptly and passes almost due east for nearly three-fourths of a mile. Along the east-west portion the disturbance takes the form of a fault, although the beds in a general way dip away on both sides of the fault line. The line of fracture may be traced from the dome of the anticline in the eastern wall of Anticline Canyon, in the eastern part of the SW. ¼ sec. 12, to a point less than one-fourth mile northeast of the Commercial Petroleum Company's well No. 1 in the SE. ¼ sec. 12. The beds on the southern side of the fault are inclined in a southerly direction with the dips varying from 60° or 70° near the fracture to 35° or 40° some distance south of it. North of the fracture the beds dip about 20° NE. and abut sharply against the steep south-dipping beds. From the eastern line of the SE. ¼ sec. 12 the line of fracture apparently bends abruptly toward the southeast and dies out beneath the superficial deposits of Alcalde Canyon.

A minor disturbance, probably intimately connected with the one just described, is developed in an east-west ridge in the NE. ¼ sec. 7, T. 21 S., R. 15 E. An examination of the surface geology of this region, beginning at the railroad cut in the NW. ¼ sec. 8, T. 21 S., R. 15 E., discloses, first, coarse sandstone beds dipping N. 35° E., at angles of 10° to 50°; westward from here along the crest of the ridge dips of N. 25° W. 16° are encountered; then dips of 20° a little farther toward the west, and finally, where the strike of the bed swings around toward the northwest, dips as high as 40°. Northwest from this maximum dip the beds drop to 30° northeast and finally to the prevailing dip of 18° to 20° along the western side of sec. 6.

A third line of disturbance is visible in the small bluff on the northwest side of Alcalde Canyon immediately north of Alcalde station. This is a sharp anticlinal fold in gray and brown shale with a dip of 20° S. 53° W. on the one side, and of 70° N. 55° E. on the other. Mount Hamilton well No. 1 is drilled practically on the axis of this anticline less than one-fourth mile from the bluff mentioned. An examination of the territory northwest of the Mount Hamilton well, embracing the territory along the contact between the Knoxville-Chico and the Tejon, discloses dips that apparently indicate a northwestward continuation of the anticline as far as the SE. ¼ sec. 10, T. 21 S., R. 14 E. The beds in this region are lying so nearly horizontal and have been so affected by landslides that it is impossible to determine definitely the course of the line of disturbance. This structural feature, however, has no apparent influence whatever upon the oil-bearing beds, but is described simply to indicate the localization of the forces producing folding in the beds.

Still a fourth line of disturbance enters the area under discussion in the southwestern part of sec. 7, T. 21 S., R. 15 E. This is a syncline which is prominently developed farther south and has been described in the discussion of the area south of Waltham Creek (p. 66). In the southwest corner of sec. 7 this syncline produces dips of 40° S. 20° W., while a short distance south the same bed dips 30° nearly due east, a little farther south 25° in the same direction, and still farther south 20°. This syncline is apparently associated with the Anticline Canyon flexure, but the relations between the two are obscured at the critical point along the south line of sec. 7 by the detrital material of Waltham Creek.

In connection with the folding and faulting which has taken place in sec. 12 it might be well to amplify the description of the geology in the vicinity of the Commercial Petroleum well No. 1 in the southeast corner of the SE. ¼ sec. 12, T. 21 S., R. 14 E. A section along the surface of the ridge northward from this well shows the following strata, all dipping approximately due south about 60°:

Section in Miocene north from Commercial Petroleum Company's well No. 1, sec. 12, T. 21 S., R. 14 E.

	Feet.
Soft sand, to	30
Pebbly sand	40
Soft sand	180
Coarse sand with hard dark layers ("shells")	240
Fine pebbly sand (dipping due south 60°)	255
Alternating coarse sandstone and pebbly sandstone beds with a particularly hard brown sand layer at the base	320
Soft blue shale and sandy shale	620
Coarse pebbly sand, the last half hard and containing silicified wood fragments (dip is 50° south)	710
Gray sand with one or two hard streaks	760
Soft blue gypsiferous shale	790
Medium to coarse gray sandstone	820

At 820 feet is the fault line extending in a direction S. 80° E. The downthrow is on the north and is probably at least 200 feet. The beds along the trace of the fault are of a purplish and pink tint, this discoloration probably being due to petroleum which has seeped up along the fault. A comparison of the above surface section and the log of the Commercial Petroleum well indicates the reason for the discrepancy between this well log and those of the wells in the sec. 6 area. In the Commercial Petroleum well the beds penetrated dip about 60°, while in the sec. 6 area the beds dip less than 20°. The water which occurs in the Commercial Petroleum well is probably of local extent and is to be associated with the fault line which apparently is cut by the well near the latter's junction with the oil sand. It is the belief of the writers that it would be impossible to put down wells in this faulted area and obtain the same or even approximate results in any two. The region about the corners of secs. 12 and 13, T. 21 S., R. 14 E., and secs. 7 and 18, T. 21 S., R. 15 E., is the center of a number of complex disturbances, which, it is believed, have locally so complicated the underground geology as to make the exploitation of the oil sands difficult if not impossible.

GEOLOGY OF THE WELLS.

The wells of this area lie for the most part in the angle where the formations bend from a strike of south and southeast to a strike of east or east-southeast. This change in strike is caused by the line of disturbance which passes down Anticline Canyon and bends abruptly east in the SW. ¼ sec. 12, T. 21 S., R. 14 E. The eastward continuation of this line of disturbance across sec. 7, T. 21 S., R. 15 E., is the cause of the abrupt turning to the east of all of the formations on the flanks of the great monocline on the west side of Pleasant Valley. It will be noticed by an examination of the contour map (Pl. II) that the formations have a practically uniform dip of about 18° or 20° down to the edge of the more pronounced hills. At the edge of the hills the dip flattens out to an angle of about 5° or 6°. It should be observed in this connection that the topography in a general way reflects this change in dip. This is an important item to remember, as in other parts of the field where there are no wells and in which surface outcrops are lacking it may be possible to judge in a general way of the position of the underground formations by a critical examination of the topography of the region under observation. As a result of the bowing of the strata the dips are apparently steepest in sec. 36, but flatten out and become more regular north of this area. In the southern part of sec. 6 and also the northern part of sec. 7 the dips are very steep at the surface outcrop. The locus of the steep dip apparently extends from the surface underground in a northerly direction and has its maximum effect on the oil sands in the NW. $\frac{1}{4}$ sec. 6 and the SE. $\frac{1}{4}$ sec. 36. Details of the change in dips and strike are indicated by contours on the map (Pl. II) and will not be discussed further here.

All of the wells within this area start down in the soft surface sands and clays, which, below the uppermost superficial stratum, are believed to belong to the Etchegoin or possibly the Paso Robles formation. Before reaching the uppermost oil zone (zone B), the wells pass through four or five well-defined zones of sandstone with as many interbedded layers of soft blue shale. Many of the sands carry pebbles up to the size of a marble, and some of the blue shales are also pebbly. Water sands are encountered at various depths, some of them producing large quantities of more or less mineralized water. The Lucile well No. 1 and the West Coalinga well No. 1 produce a great deal of water, but from entirely different rocks, the first from the Jacalitos (upper Miocene) the latter probably from the Knoxville-Chico (Cretaceous). Some very hard sandstone shell layers are encountered in the wells and in one or two places these appear to be rather persistent laterally. The hard layer reported as the "Big Shell" in some of the wells is apparently not the stratum so designated in others.

The first oil zone (zone B) varies in thickness from about 60 to 150 feet. In some of the wells it is reported as nearly solid sand, while in others it is a zone of alternating sandstone and shale. Oil or gas, or both, are reported from it in all of the wells except Shreeve No. 1, but it is believed that indications of petroleum must have been found in this well and overlooked by the driller, or else they were not considered of enough importance to record in the log. So far as known none of the wells in this area produce from this zone. The individual sands of zone B vary from fine-grained thin-bedded layers intercalated with sandy shale to coarse conglomeratic sand carrying small cobbles.

As previously mentioned, this zone may be studied in the east wall of the canyon running up to the Henshaw water well (SW. ¼ sec. 35, T. 20 S., R. 14 E.) about half a mile southeast of this well.

Oil zone B is underlain by a persistent stratum of mineralized water, either salt or sulphur or both, in nearly all the wells. In some this flow of water was encountered at the base of a hard sandstone shell underlying the oil strata, but in others it is reported in the lowest oil sand of the zone. Oil zone B is separated from the lower or zone D by between 150 and 200 feet of shale and shell. Some water sands and tar sands are reported in the space between zones B and D in some of the wells, but these do not appear to be very persistent. Only three of the wells have so far penetrated zone D and these touch only its uppermost sands. The reason for this is generally because the gas pressure is great enough either to make the well flow or to fill it up with sand. The uppermost beds of zone D are fine grained and carry oil of fairly light gravity. Oil of 32° B. has been reported in one of the wells, and the gravity of all the upper beds seems to range from this down to 26° B.

Below the zone of light oil sands is a coarser sand carrying fossil shells and believed to be the same as the bed at the base of bed 2 in the section on page 101. The oil from this lower zone is much heavier than that from the upper, averaging about 16° or 17° B.; the production also is very much greater from the lower sand than from the upper finer sands, and is, therefore, tapped wherever possible. It is the belief of the writers that this lower oil sand will furnish long-lived wells, for holes that simply tap its uppermost layers are very productive and the 150 or 200 feet of sands that are believed to underlie the tapped bed are doubtless heavily impregnated with oil.

SEC. 2, T. 21 S., R. 14 E., AND VICINITY.

GEOLOGY OF THE WELLS.

Underground conditions in the E. ½ sec. 2, T. 21 S., R. 14 E., and in the southern part of sec. 35, T. 20 S., R. 14 E., have been tested by the wells of the Sunnyside Oil Company (Henshaw water well) and the Westlake-Rommel Oil Company. The wells penetrate the northeast-dipping beds of the Vaqueros formation (lower Miocene), which overlie the steeply tilted Knoxville-Chico (Cretaceous) strata exposed at the surface toward the west. The oil in this area is believed to have percolated along the basal (zone D) sands from the east, where these sands overlie the shales of the Tejon (Eocene). Only four wells have so far been put down in this area; three were sunk several years ago by the Westlake-Rommel Oil Company, and one (the Henshaw water well) was put down by Captain McClurg for the Sunnyside Oil Company in 1897. The logs of these wells indicate that the petroliferous zone is from 100 feet to 120 feet thick and consists of medium-grained sands interbedded, especially toward the middle of the zone, with fine clays and harder sand layers. The sand carries a little heavy oil and in the Westlake-Rommel wells is said to have yielded no gas. This lack of gas would be expected in an area so close to the outcrop of the oil sands where the gas would have an opportunity to escape from the petroliferous beds. Water is found associated with the oil in the uppermost layer of this zone in one of the wells and is found abundantly in the sands just beneath the oil zone. In addition to the four wells mentioned, tunnels were run in on the outcrop of the oil sands in the E. ½ sec. 2, but did not obtain enough oil to pay for their operation.

It is believed that the Henshaw well obtains its water from a sand in the Knoxville-Chico (Cretaceous), as the depth at which the sand is penetrated is considerably lower than the base of the Vaqueros formation. As the Knoxville-Chico beds in this region are highly tilted, wells will be able to tap the Henshaw water sand along a narrow band only. As the strike of the Knoxville-Chico is here about east-northeast, it is believed that this band strikes in a direction north-northwest or south-southeast of the Henshaw well.

PRODUCT.

The daily yield of the individual productive wells in the area between Waltham Creek and the southern part of sec. 36 ranges from about 100 barrels in those on the dip to about 800 barrels in the deeper holes. An initial production of over 1,500 barrels a day is said to have come from one of the wells. Oil of 26° B. gravity is yielded by sands at the top of the lower zone (zone D), and as high as 175 barrels of oil a day is said to have been produced by one well from these sands alone. Below the light oil sands are coarser and more productive layers which yield the bulk of the oil for this territory. The gravity of the petroleum from this last horizon is between 16° and 17° B. The oil in the light oil sands is brown; that in the zone of heavier oil is black.

KREYENHAGEN FIELD.

LOCATION.

The region south of Coalinga as far as Dudley, Kings County, including the Kettleman and Kreyenhagen Hills and Reef Ridge, has been known for many years as the Kreyenhagen oil district. For the sake of brevity of discussion in the present report this territory has been included as a part of the Coalinga district and has been divided into two fields, the Kreyenhagen field and the Kettleman Hills field. The area discussed as the Kreyenhagen field lies on the southeastern flanks of Reef Ridge and extends from the general region of Jacalitos Creek to Dagany Gap, 3½ miles southeast of Dudley. The area in which oil development has been carried on constitutes a narrow band between Canoas Creek and the region of Big Tar Canyon.

GENERAL GEOLOGY AND OCCURRENCE OF OIL.

Reef Ridge and the region immediately adjacent to it both southwest and northeast lies on the eastern flank of the great monocline of rocks which forms the main Diablo Range. The formations involved in the geology are the Knoxville-Chico (Cretaceous, conglomerates, sandstones, and shales), the Tejon (Eocene, sandstones and shales), the Vaqueros (lower Miocene, sandstone and shale), the Santa Margarita (upper middle Miocene, shale), and the Jacalitos (upper Miocene, sandstone, shale, and gravel). The oil, as in the region of the Coalinga field proper, is believed to have originated in the shales of the Tejon formation, but has migrated to the underlying sandstones of the Tejon, into sands interbedded with the shales of the Tejon, and into the overlying Vaqueros sandstone. Evidence of the petroliferous character of the Tejon and Vaqueros is found in numerous tar springs which emanate from those formations at various points within the area under discussion. Such, for instance, are those in Canoas Creek, which come from the upper part of the Vaqueros; those on or near the Clark ranch farther south in the vicinity of Garza Creek in the same formation as the latter; the famous tar spring in Big Tar Canyon, which comes from the upper part of the Tejon; and the springs in Little Tar Canyon and north of it, which emanate from the upper part of the Tejon. Numerous other seepages and springs are found along the outcrop of the Tejon and Vaqueros; but within the area mapped none, to the knowledge of the writers, are found farther north than Canoas Creek nor farther south than the head of Little Tar Canyon.

Indications of petroleum are found in the basal shale layers in the Tent Hills anticline, 2 miles southeast of Dudley, but no true seepages are known between the one in Little Tar Canyon and Sulphur Spring in the Devils Den district. The Castle Mountain fault, which cuts off the Tejon and Vaqueros near the head of Little Tar Canyon, is believed also to eliminate these same formations under the Santa Margarita southward for a considerable distance below the head of Little Tar Canyon. Owing to the steep dip in the formations along Reef Ridge the petroliferous zone is necessarily very narrow. The extent of the zone in which it seems possible that productive wells may be put down is shown on the map (Pl. I). Water accompanies the oil in all of the seepages along this belt and has caused the failure of many of the test holes that have been put down in the area.

GEOLOGY OF THE WELLS.

The wells in the Kreyenhagen field may be divided into two groups; those which have been sunk in the Tejon (Eocene) formation, and those which start in strata above or younger than the Tejon. The wells in the first group, enumerated from north to south, include those of the Kreyenhagen Oil Company, Kings County Oil Company, Consolidated Oil and Development Company, Baby King Oil Company, and Avenal Land and Oil Company. The wells in the second group enumerated in the same direction include those of the Black Mountain Oil Company, Kings County Oil Company, St. Lawrence Oil Company, and that of the El Cerrito Oil Company, formerly known as the Anderson well.

Tejon formation.—The two wells of the Kreyenhagen Oil Company are located on Canoas Creek in the SE. ¼ sec. 32, T. 22 S., R. 16 E. Both wells start in the shale in the upper part of the Tejon, the southermost, well No. 1, beginning lowest in the formation. This well (No. 1) penetrated 650 feet of dark-colored shale, finding water at 125 and at 400 feet, and ended in 10 feet of oil sands.

An examination of the geology immediately south of this well indicates that the oil sand is very much thicker than indicated; just how far below the shale the sand is impregnated it was not possible to determine accurately, but on the surface the sand showed signs of petroleum for a thickness of over 100 feet. Well No. 1 is said to have yielded about 15 barrels a day at the start, soon falling to 5 or 6 barrels. The product is said to be a light-green oil, gravity between 37° and 38° B. No water accompanied the oil. Well No. 2 of the same company is located north of and higher in the formation than well No. 1. It is said to have found traces of oil at 1,000 and 1,100 feet and to have attained a depth of about 1,200 feet, at which point water was encountered. This last well never produced commercial quantities of oil.

The Kings County Oil Company sunk a well in the SW. ¼ SW. ¼ sec. 3, T. 23 S., R. 16 E. This location implies that the well started somewhere about the middle of the band of the Tejon formation as developed in this vicinity. The well is said to have passed through black shale, blue sandstone, and brown sandstone containing oil, but was abandoned on account of water.

The Consolidated Oil and Development Company sunk two wells in the Tejon (Eocene) formation in the NE. ¼ sec. 10, T. 23 S., R. 16 E. One of the wells attained a depth of 1,100 feet and is said to have obtained a good showing of 20° B. amber-colored oil at a depth of 1,050 feet. The difference in gravity between this oil and that obtained from the same formation in the Kreyenhagen well is not easily explained.

The well of the Baby King Oil Company is located in the canyon of the first stream west of Big Tar Canyon, immediately behind Reef Ridge, in the NE. ¼ sec. 11, T. 23 S., R. 16 E It starts in strata lying near the contact between the Tejon (Eocene) and Vaqueros (lower Miocene) formations. It is said to have struck oil of 30° B.

gravity at 400 feet, and oil of 18° B. gravity at 1,100 feet; a short distance below this last point flowing water was encountered. At the time of the writer's visit, in September, 1907, the well was flowing about half a miner's inch of water, accompanied by occasional blebs of black heavy oil and some gas.

The Avenal Land and Oil Company has two wells in the E. ½ E. ½ sec. 18, T. 23 S., R. 17 E., not far from the famous tar spring in Big Tar Canyon. Well No. 1, the westernmost of the two, starts down in the soft oil-stained sand beds of the Tejon (Eocene), or possibly Vaqueros (lower Miocene), immediately underlying the lowest hard sandstone bed of the Vaqueros. The log of this well is as follows:

Log of well No. 1, Avenal Land and Oil Company, E. ½ E. ½ sec. 18, T. 23, S., R. 17 E.

	Feet.
Adobe	20
Oil sand with water	70
Blue water sand	140
Clay	235
Shale	521
Oil sand	555
Shale	590
Sand showing traces of oil	635
Shale	802
Blue clay	900
Sand with traces of oil (not finished)	984

This well is said to have yielded less than 2 barrels a day of dark-colored 28° B. oil. Well No. 2 starts well down in the Tejon and is said to have gone through soft sand to 1,045 feet, where a productive sand was encountered. It yielded some oil when pumped by a bailer.

Formations above the Tejon.—The Black Mountain Oil Company sunk two wells in the SW. ¼ NW. ¼ sec. 33, T. 22 S., R. 16 E. Both start in the dark shale of the Santa Margarita formation and obtain their oil from the top of the Vaqueros sandstone. The log of well No. 1 of this company is as follows:

Log of well No. 1, Black Mountain Oil Company, SW. ¼ NW. ¼ sec. 33, T. 22 S., R. 16 E.

	Feet.
Dark-colored shale	80
White sand	85
Dark-colored shale	400
Light-colored shale	550
Shale and sand with oil	570
Light-colored shale	640
Oil sand	660
Shale	700
Oil sand	720

This well is said to have produced 5 or 6 barrels of black, 18° B. oil. The second well is located 600 feet north of No. 1, but no data concerning it are available.

The Kings County Oil Company sunk a well in the SW. ¼ NE. ¼ sec. 3, T. 23 S., R. 16 E., which is believed to start toward the bottom of the Santa Margarita (upper middle Miocene) and to obtain its oil from the Vaqueros (lower Miocene). The log of this well is as follows:

Log of well of Kings County Oil Company in SW. ¼ NE. ¼ sec. 3, T. 23 S., R. 16 E.

	Feet.
Clay and soil	12
White shale	29
Black shale	65
Black sand	67
Black shale	90
Hard gravel (heavy oil at 240 feet)	120
Black shale	275
Gravel	285
Black shale	410
Blue sand rock	450
Water sand	490
Blue sand rock	540
Sand	556
Clayey sandstone	600
Black shale	660
Clayey sandstones	696
Hard shale	720
Hard rock, sandstone predominating	950

Another well was also started by the same company but was never finished.

The St. Lawrence Oil Company is said to have sunk a well in the SE. ¼ NE. ¼ sec. 12, T. 23 S., R. 16 E., which encountered oil near the bottom. This well doubtless began in the shale of the Santa Margarita and penetrated the oil sands at the top of the Vaqueros (lower Miocene).

A. M. Anderson and associates (El Cerrito Oil Company) have been drilling the past summer on a well in the NW. ¼ sec. 14, T. 23 S., R. 17 E. The well starts near the contact between the Etchegoin (upper Miocene) and Paso Robles (Pliocene-Pleistocene) formations, and is said to have been located on the evidence of a supposed oil sand outcrop a few hundred feet south of the well site.

KETTLEMAN HILLS FIELD.

LOCATION.

Development work within the Kettleman Hills has been confined to their northern portion, all the wells started having been put down on the flanks of the hills at some distance from the axis of the Coalinga anticline, which runs parallel with and east of the topographic axis of the hills.

GEOLOGY AND INDICATIONS OF OIL.

The formations that rise to the surface in the anticline are the Etchegoin and the Paso Robles, described fully on pages 46–61. The structure of the hills is that of a simple arched anticline, with low dips toward the axis and steeper ones toward the flanks. The maximum dip on the northeastern flank is about 31°, that on the southwestern flank 45°.

One of the Government land surveyors who visited the Kettleman Hills over twenty years ago informed the late Mr. W. P. Kerr (who informed the senior author) that he had seen what he supposed was an oil seepage in the northeastern flank of the hills in the southeastern part of T. 21 S., R. 17 E., or the northeastern part of T. 22 S., R. 17 E. Neither Mr. Kerr nor the senior author, who visited this locality in 1907 and made a careful examination, were able to find any traces of an oil seepage in this region, although places where mineral waters have oozed from the rocks in the rainy season were noted in several instances. It is believed that the Kettleman Hills offer no direct surface evidence of petroliferous deposits.

GEOLOGY OF THE WELLS.

Seven or more wells have been put down in the hills and none of these have been successful, but owing to their position and comparatively slight depth they have made no adequate test of the territory. (See p. 120 for conclusions concerning future development.) Two wells, the Gibbs and Oceanic, are on the northeastern flank of the anticline; the other five are on the southwestern flank. None are within the area outlined as possibly productive on the map (Pl. I).

Following are descriptions of the wells that have been put down in the Kettleman Hills:

Gibbs Oil Company, located in eastern part of the NW. ¼ sec. 28, T. 21 S., R. 17 E., farthest north of any in the Kettleman Hills. Starts in beds near the top of the Etchegoin (upper Miocene) formation about 1 mile east of the axis of the Coalinga anticline.

Oceanic Oil Company's well; located in the NW. ¼ sec. 1, T. 22 S., R. 17 E., on northeastern flank of Coalinga anticline on one of the spur ridges running northeast from the main Kettleman Hills divide. Starts in the uppermost blue-gray sands of the Etchegoin; said to have penetrated blue sands and shales and to have yielded large quantities of water; depth, 950 feet.

Stanislaus Oil Company's well; located in the NW. ¼ sec. 4, T. 22 S., R. 17 E. Starts in beds well up in Etchegoin formation, a little less than a mile southwest of the Coalinga anticline; is said to have attained a depth of about 1,000 feet without encountering any oil.

Iowa Oil Company's well; located in the SW. ¼ sec. 4, T. 22 S., R. 17 E., not far distant from and on the same ridge as that of the Stanislaus Oil Company. Conditions in the two wells are practically the same and results obtained were similar.

Florence Oil Company's wells; both located in the NW. ¼ sec. 15, T. 22 S., R. 17 E. On the southwestern flank of the Coalinga anticline about a mile from the axis; near the surface penetrate strata at the bottom of the Paso Robles formation. Are said to have attained a depth of 720 feet and to have encountered considerable gas but no oil.

Esperanza Oil Company's wells; both located in the SW. ¼ sec. 14, T. 22 S., R. 17 E. One attained a depth of 1,100 feet but was abandoned on account of water; the other reached 840 feet when drilling operations were suspended. Start in the uppermost beds of the Etchegoin formation, on southwestern flank of the anticline something over a mile from the axis.

Stockton Oil Company's well; located in the NW. ¼ sec. 30, T. 22 S., R. 18. E., farthest south of any test well in the hills. Starts in beds near the contact between the Etchegoin and Paso Robles formations, on southwestern flank of the anticline about 2 miles distant from the axis. Is said to have attained a depth of 670 feet, with no results in the way of gas or oil.

FUTURE DEVELOPMENT.

GENERAL STATEMENT.

The conclusions here to be discussed as to the course that future development will take in the Coalinga district are based on the belief that the petroleum is originally derived from the shales of the Tejon (Eocene) formation and that on migration it collects both in the sands interbedded with these shales and in the porous portions of the overlying Miocene. All of the conditions indicate that this belief is well founded and is equivalent to the truth.

Several requisite factors enter into the question of the accumulation of the petroleum and the possibility of its extraction in commercial quantities. Among these are the following, briefly stated:

(*a*) An adequate thickness of the shales of the Tejon (Eocene) to yield commercial quantities of oil.

(*b*) A cause for the migration of the oil from its source in the organic shales. This cause is believed to be supplied by the tendency of oil to migrate by diffusion through certain media, such as dry shales; it may be and doubtless is in certain instances augmented by hydrostatic pressure wherever water has come in contact with the petroleum.

(*c*) Associated porous beds occupying such a position relative to the source of the oil and to impervious barriers as to permit of the petroleum passing from the source into the final reservoir and being there confined by impervious strata. Wet shale or clay and certain fine-grained water-impregnated sands are believed to be among the effective barriers to the migration of the oil.

(*d*) Occurrence of the accumulations at a depth far enough below the surface and distant enough from outcrops to preclude the escape of the lighter hydrocarbons, and still at depths which may be profitably reached by the drill. The areas within the lines shown on the map (Pl. II) as bounding the possibly productive territory are those in which the top of the supposed oil zone has been calculated as possibly within a vertical distance of 4,500 feet from the surface. A depth of 4,500 feet below the surface has been arbitrarily taken as the maximum to which it is possible to drill by present methods in the region under discussion, as this is about the maximum depth of holes in California which have been drilled with a standard rig. It may be possible to go deeper than this, but for the present this limit seems sufficiently great. Whether or not a well can be profitably drilled depends upon so many factors, such as quantity of oil produced compared with cost of drilling, price of oil, etc., that local conditions must determine the result in each specific case.

It seems very unlikely that oil, even in small amounts, will be found in any of the rocks underlying the Tejon (Eocene)—that is, in the Cretaceous or Franciscan formations (see map, Pl. I)—while it is quite likely that it will be found in the Tejon and in the formations immediately overlying the latter, whether or not in paying quantities depending on the factors above enumerated. In the following paragraphs it is the intention of the writers to give their personal opinion as to the probabilities of the occurrence of petroleum in regions not yet thoroughly tested by the drill. It must be borne in mind, however, that absolute determination, by work on the surface, of the occurrence or nonoccurrence of oil in any one locality is not possible. The best that can be done is to calculate the degree of probability on the basis of surface indications and structural conditions.

AREAS DISCUSSED.

The areas for which the probabilities of the occurrence of petroleum is discussed in the following paragraphs are as follows: Northwest of Eastside field, Eastside field, Anticline Ridge and Guijarral Hills, Westside field, south of Waltham Creek on Jacalitos anticline, Reef Ridge south to Dagany Gap, and Kettleman Hills.

NORTHWEST OF EASTSIDE FIELD.

The well of T. C. Oil Company in sec. 2, T. 19 S., R. 15 E., has proved the eastern flank of the Coalinga anticline as far north as the northern edge of the area shown on the map (Pl. I). Near this point the beds bend from a strike of almost due north to one of N. 30° or 40° W., the dip at the same time steepening to 30° or more in secs. 34 and 35, T. 18 S., R. 15 E. The writers have examined the country only as far north as the middle of sec. 29, T. 18 S., R. 15 E., but up to this point the shales of the Tejon (Eocene) were found well developed, and it is therefore believed that the overlying Miocene sands will be found productive as in the region farther south. The steepening of the dip of the beds in this undeveloped territory will necessarily narrow the productive ground materially, decreasing it to a band less than 2 miles wide, whereas southward in the middle of the Eastside field, where the dip is approximately only 16°, the width of the productive belt is over 3 miles. Toward the northern end of the Eastside field as mapped in this report, and still farther northwest, only zone D, the lower part of the Vaqueros (lower Miocene), it is believed, will be found productive, and here not as prolifically as farther south, owing to the thinning of the productive zone.

EASTSIDE FIELD.

Little need be said concerning the probable development in the already well-proved areas of the Eastside field, as their future may be inferred from a perusal of the paragraphs devoted to the discussion of the geology of their wells. It should be borne in mind, however, that the lower part (and what in sec. 28 and the western part of secs. 22 and 27 is the richest part) of the oil measures has not been tested in those wells farthest down the dip and should yield good returns for the extra cost of deepening if water is not encountered at the greater depth; and there is no evidence at present indicating that water exists at the base of the oil in this area. It is believed that oil in commercial quantities will never be found above the "Big Blue" in the Eastside field (a possible exception to this may be the "St. Paul sand" in sec. 34), so that wells put down outside of the limit of those in which the bottom of the "Big Blue" is penetrated at less than 4,500 feet will probably never pay.

Two factors militate against the successful exploitation of the southwestern flank of the Coalinga anticline immediately southwest of the developed Eastside territory. These are (*a*) the steep dip (almost perpendicular in places) of the beds, which carries the oil zone rapidly downward to great depths toward the southwest, and (*b*) the more locally disturbed condition of the various beds throughout this zone of steep dip. It is believed that at least the lower part of the oil zone along this flank will be found more or less productive wherever it can be reached, but it is also believed, and this belief is strengthened by the experience of those who have drilled in the territory, that the disturbed conditions of the beds will make the shutting off of the water difficult or sometimes impossible, thus hindering the most successful manipulation of the wells. Toward the southeastward the dips lessen in degree and the resulting conditions are somewhat more favorable for successful wells.

Within the area of the shale and interbedded sandstone of the Tejon (Eocene) lying between the Cretaceous (Chico) beds on the west and the overlying Vaqueros (lower Miocene) sandstone on the east and extending from Oil City northward beyond secs. 29 and 30, T. 18 S., R. 15 E., it is believed that favorable locations for productive wells yet remain undeveloped. Surface indications lead to the belief that wherever in this area the sands interbedded with the shale of the Tejon formation are of a porous character they contain appreciable and in some cases probably commercial quantities of petroleum at available depths. As the quality of the oil obtained from the Tejon sands is usually considerably higher than that found in the Miocene, small producers in the Tejon area should pay where the same production would involve a loss elsewhere. It is believed that a well site so chosen that the prospective sand would be encountered at 600 feet or more below the surface would be the most favorable for exploiting the Tejon territory. The same conclusions as those just expressed have been reached for practically the whole band of Tejon extending intermittently along the western edge of the Miocene in the Coalinga district from sec. 29, T. 18 S., R. 15 E., to Little Tar Canyon, northeast of Dudley. Furthermore, it is believed that productive sands in the Tejon may be tapped by wells which start in overlying formations, but predictions as to favorable locations for such tests would be unreliable owing to the unconformable relation of the overlying beds to the Tejon.

ANTICLINE RIDGE AND GUIJARRAL HILLS.

Throughout its entire length along the southwestern edge of the developed territory in the Eastside field the axis of the Coalinga anticline dips southeast at about 9° until in the northwestern part of sec. 2, T. 20 S., R. 15 E., it assumes an angle of approximately 4°. The territory along this comparatively low-dipping portion of the anticline has been proved productive as far southeastward as the middle of the NW. ¼ sec. 2, T. 20 S., R. 15 E. Southeastward from this last-mentioned locality the indications for productive wells are good. The productive territory will be limited to that portion of the anticline where the productive sands lie at such a depth as to be profitably reached by the drill.

In drawing conclusions as to just how far southeastward along the axis of the anticline this limit will be two factors have to be taken into consideration: (*a*) Dip or pitch of the anticline, and (*b*) thickening of the formations toward the southeast.

Regarding the first factor (*a*) surface evidence indicates a dip of about 4°, or something like 350 feet to the mile. Certain evidence offered by the well logs of the territory in question, however, indicate a much lower dip, about 2°, or 185 feet to the mile.

Regarding the second factor (*b*) a conservative estimate indicates that at its nearest point to the surface in the northern portion of the Kettleman Hills the top of the oil-bearing zone may lie within 3,500 feet of the surface. This depth assumes a very considerable increase in the thickness of the formations above the oil-bearing Vaqueros over the thickness of the same formations in the Eastside field. Just where this thickening of the beds begins it is not possible to find out, but it is believed to commence toward the lower end of Anticline Ridge; that is, along the Coalinga anticline a little way north of the railroad. Taking all of the evidence into consideration, it seems probable that the conditions indicated by the contours on the map (Pl. II), a dip of 4°, or 350 feet to the mile, along the anticline, will be found to be the average as far southeastward as the Guijarral Hills, although it may possibly be less in secs. 2 and 12, T. 20 S., R. 15 E., and possibly somewhat more in the region of the Guijarral Hills. Owing to the much steeper dip on the southwestern flank of the anticline than on the northeastern, the productive ground will be found to extend much farther away from the axis on the latter flank than on the former. as indicated by the contour map.

WESTSIDE FIELD.

Owing to the rapid thinning and even entire pinching out of the Vaqueros or lower Miocene oil-bearing formation toward the western edge of the Westside field, predictions as to the exact depths at which the top of this formation will be encountered at any particular point are unusually hazardous. For this reason the top of the lowest of the Jacalitos (upper Miocene) petroliferous zones (zone B) was chosen for contouring, as this latter extends over the whole region, although both at the northern and the southern ends of the field it is not commercially productive. There are no known reasons at present for believing that any of the territory in the main portion of the Westside field under which the productive measures lie at a greater depth than 500 feet are unproductive. Local conditions, such as the extreme thinness of the shale or clay separating water from oil sands, may make the manipulation of certain wells more or less difficult or possibly unsuccessful, but there is no evidence of "bottom" or "edge" water in any of the wells so far drilled that condemns any of the territory generally considered as proved. On the contrary, evidence is available indicating that in many of the wells which have penetrated but a short distance into the oil-bearing zone there are underlying and untouched sands even more productive than those already developed. It is the belief of the writers that in this field, as in the Eastside, the sands become more productive the nearer they lie to the brown shale of the Tejon. It seems worth while, therefore, in those areas where conditions are such that water could be plugged off if encountered below the already tested productive sands, to deepen to the beds immediately overlying the brown shale. Such a procedure, however, will require great care in avoiding the flooding of the upper productive beds if water should happen to be encountered in the oil-bearing series of beds.

It is believed that considerable commercially productive territory is yet untested in the southwestern portion of the Westside field, especially north and northeast of the fault (see Pl. II) which extends east and west through the middle of the SW. ¼ sec. 12, T. 21 S., R. 14 E. The extent of this productive area is believed to depend on whether the various Miocene sands are underlain by the Tejon (Eocene) formation or by Knoxville-Chico (Cretaceous) rocks. In the former case it is believed that the beds will be found commercially productive; in the latter case, except within half a mile or so of the contact between the Tejon and the Knoxville-Chico, it is believed the oil sands will be dry or only poorly saturated. Direct evidence of the trend of the contact between the Knoxville-Chico and Tejon ceases in the southwest corner of sec. 26, T. 20 S., R. 14 E., because south of there it is entirely covered by the later formations. At this locality its direction is about S. 25° E., but this strike is believed to swing eastward so that the contact passes north of the corner of secs. 1, 12, 6, and 7. The partial failure of the well in the SE. ¼ sec. 12 is believed to be due entirely to local conditions accompanying the fault to the north of the well, while the water in the well in the SE. ¼ sec. 12 comes from beds believed to be Knoxville-Chico.

JACALITOS ANTICLINE.

The first locality south of the southwest corner of sec. 26, T. 20 S., R. 14 E., where the Tejon (Eocene) formation is definitely known, is in Sulphur Spring Canyon in the southern part of sec. 23, T. 22 S., R. 15 E. As mentioned above, there is evidence that the contact between the Knoxville-Chico and the Tejon passes north of the corner of secs. 1 and 12, T. 21 S., R. 14 E., and secs. 6 and 7, T. 21 S., R. 15 E. Just how this contact trends between this corner and the Sulphur Spring Canyon locality is not definitely known, but it is the belief of the writers after a study of the intervening region that the contact soon bends to the south after passing into the northern part of sec. 7, T. 21 S., R. 15 E., then swings around to a southwesterly trend, continuing this down to Sulphur Spring Canyon, in a somewhat similar way to that followed by the later beds, now exposed over the area. The relation of the whereabouts of this contact between the Knoxville-Chico and Tejon to the future development of the region is obvious when it is remembered that only those portions of the Miocene sands which overlie the Tejon (Eocene) are believed to be productive. It is the opinion of the writers, therefore, that the basal Miocene sands are likely to be commercially oil bearing only in the area northeast of a line which passes in a general way southwesterly from the eastern part of sec. 7, T. 21 S., R. 15 E., to sec. 23, T. 22 S., R. 15 E. Passing southward from the region immediately north of Alcalde Canyon the formations which overlie the oil-bearing Vaqueros thicken rapidly until in the region of Jacalitos Creek, the Jacalitos formation (upper Miocene) alone is 3,500 feet through, whereas in the Alcalde Canyon region it is less than 1,500 feet. This great thickening of the beds above the oil zone toward the south will necessitate much deeper wells than would be required if the formations were uniform. At the axis of the Jacalitos anticline on Jacalitos Creek, where the supposedly productive zone approaches nearest to the surface, it is estimated that the top of the Vaqueros is about 3,600 feet below the surface. As the axis plunges northward north of the creek and southward along the anticline from the high hill immediately south of the creek it is obvious that the territory possible of development is very limited. The northeastern flank of the Jacalitos anticline dips much more steeply than the southwestern flank, so that the band of productive ground on the northeast will be much narrower than that on the southwest. Owing to the uncertainties incident to the complicated structure at the northern end of the Jacalitos anticline in sec. 18, T. 21 S., R. 15 E., and the rapid rate of thickening of the beds, quantitative statements concerning the depth of the oil zone below the surface at any one point will not be attempted for the region south of Alcalde Canyon. A suggestion as to the probable depth at which the oil zone lies may be gathered from the statement that it is struck at about 700 feet below sea level (1,600 feet below the surface in the NW. ¼ sec. 18, T. 21 S., R. 15 E.) and as before stated is probably some 2,800 feet below sea level (3,600 below the surface) on the axis of the anticline on Jacalitos Creek. This great increase in depth occurs even in the face of the fact that the axis of the anticline is plunging (near its northwestern end as much as 15°) toward the northwest.

REEF RIDGE SOUTH TO DAGANY GAP.

The great monocline of Tertiary beds which flanks Reef Ridge on the east and forms the Kreyenhagen Hills is underlain by the Tejon formation from a point at least as far north as Sulphur Spring Canyon (in sec. 23, T. 22 S., R. 15 E.) to the head of Little Tar Canyon (in sec. 35, T. 23 S., R. 17 E.). Throughout nearly the whole extent of this Tejon band it shows unmistakable signs of its petroleum contents. Many oil seepages also occur from the Vaqueros sands overlying the Eocene, so that there is no doubt as to the presence of petroleum throughout practically the whole length of the region under discussion. Furthermore, productive wells on Canoas Creek, in Big Tar Canyon, and elsewhere (see pp. 108–111) have proved the presence of oil in commercial quantities in at least certain localities. Although the territory offers no promise of a large individual production, it is the belief of the writers that productive wells may be put down along practically the whole strip of territory from between Jacalitos and Canoas creeks to Little Tar Canyon. West of Jacalitos Creek the Tejon is apparently lacking or else is thin and insignificant; southeast of the head of Little Tar Canyon the Tejon is cut off by the Castle Mountain fault. It is therefore not likely that the productive sands extend far either northwest of Sulphur Spring Canyon or southeast of the head of Little Tar Canyon. Indications of petroleum are in evidence in the axis of the Pyramid Hills anticline, southeast of Dudley, and still farther southeastward toward the Devil's Den country, so that the extension of the productive belt in a southeasterly direction from Little Tar Canyon is probably only locally affected by the fault. The lighter oil is to be expected in the Tejon as in the Coalinga field, but the best production will doubtless be found in the Vaqueros or lower Miocene sand. The production in either case will probably not be large, for the steep dip of the beds precludes the conditions necessary for great accumulations of oil. The steep dip, however, so increases the distance through which the wells may penetrate the sand that the lack of complete saturation may be partly compensated for by increased surface of sand exposed in the well. An item that should not be overlooked in drawing conclusions concerning this strip of territory is the probable occurrence of water in or closely associated with the oil sands. Nearly all of the oil seepages in the region are accompanied by water, and many of the test wells have been abandoned on account of it, so that trouble from this source should not cause surprise to those who may undertake to exploit the region. The depth to which the oil sands along Reef Ridge may be exploited is limited by the relation between the cost of drilling plus operation and the production and value of the oil; and by whether or not the water that is apparently associated with the oil-bearing beds is "bottom" or "edge" water. These factors are determinable only by actual test. The area outlined on the map (Pl. I) as probably productive embraces all of the territory along Reef Ridge in which it is thought that the top of the Vaqueros or lower Miocene sands will be encountered at a depth less than 4,500 feet below the surface. At some localities seepages indicate that the productive zone is near the base of the formation; at other localities the evidence favors the theory that the top will be found the most productive. All of the evidence seen by the writers leads to the conclusion that productive bodies of petroleum will not be encountered in or above shale of the Santa Margarita formation, that is, above the top of the Vaqueros (lower Miocene) zone.

KETTLEMAN HILLS.

The Kettleman Hills were formed by an uplift of the sedimentary formations of this region along the Coalinga anticline. It is an interesting and important problem to consider whether this great arch, the summit of which has subsequently been in large part worn away by erosion, has brought within reach of the surface the beds which are oil-bearing a few miles away. The conditions for the accumulation and preservation of oil in this broad, regular fold would appear to be good, and the question as to the occurrence of valuable deposits resolves itself principally into two problems; (1) whether the hills are underlain by the Tejon, the original oil-bearing formation in this district, and whether oil is therefore most probably present; and (2) whether the oil-bearing beds are brought sufficiently near to the surface by the anticline to be accessible. There is no direct evidence obtainable on either of these questions owing to the complete hiding of the oil-bearing formations, if such there be, by the great thickness of overlying formations; and there will be no such evidence until a test is made by means of the drill, but the geologic facts observed in the hills and in other parts of the district afford indirect evidence of considerable importance favoring the theory that the necessary conditions mentioned above do exist.

As regards the first condition, it may be reasonably supposed that the Tejon formation underlies the whole of the foothill and valley region within at least a few miles east and southeast of its outcrop in the hills around Pleasant Valley and along Reef Ridge. There is no known reason for supposing otherwise. The San Joaquin Valley has been during long periods of geologic time a basin of depression in which deposition of sediments and subsidence have gone on, and there is evidence to show that during the Eocene, when the Tejon formation was being deposited in the sea that covered part of the area under discussion, the present Diablo Range was, at least in part, a belt of land that stood out with considerable relief and formed the shore line. The sea extended thence eastward, and unless a belt of land rose where the present Kettleman Hills stand the formation must have been deposited over their area. It is possible that the Coalinga anticline is an old axis of uplift that may have determined an area of relief in previous epochs, but it is not probable. The fact that the Cretaceous beds on Joaquin Ridge are not more disturbed than the younger ones lapping over the anticline farther east indicates that no great uplift occurred along this anticline before the latest period of movements, during which all of the formations were affected at the same time.

The same reasoning applies to the question whether the Tejon formation when once deposited over the area now occupied by the Kettleman Hills was worn away by erosion before the deposition of the younger Tertiary formations and the preservation in them of the petroleum. If no uplift of magnitude occurred, it is not likely that the formation was worn away. In fact, it was probably less eroded than in the region farther west, where it is now exposed, a region that was nearer the shore line and more subjected to disturbances. It may therefore be assumed as a good working hypothesis that the Tejon was originally deposited and still exists beneath the formations covering the surface of the Kettleman Hills. Similarly it is to be supposed that the whole succession of Tertiary formations is the same beneath these hills as in other parts of the district. Whether or not the Tejon is oil-bearing can not be told, but being so near to the extensive area in which it is petroliferous the chances are good that it is likewise so beneath these hills.

As regards the second condition, the evidence afforded by the thickness of the formations in various parts of the district must be brought to bear in order to determine at what depth the oil-bearing beds will be met. The anticline exposes along its axis a low portion of the Etchegoin (uppermost Miocene) formation, and therefore the drill will have to pierce the base of this formation and the whole of the Jacalitos (early upper Miocene) and Santa Margarita (upper middle Miocene) formations in order to reach the petroliferous beds of the Vaqueros (lower Miocene), provided that these formations are present as they have been assumed to be. The formations here probably bear a closer similarity in occurrence and thickness to the same formations on the western side of the syncline along the Kettleman Plain than they do to the formations in the Coalinga field. The oil probably collects, as it does along Reef Ridge, in the Vaqueros sandstone overlying the Tejon (Eocene) and is retarded from further upward migration by the compact shales of the Santa Margarita.

The question of the thickness of the formations may be taken up with relation to each one separately, beginning with the exposed Etchegoin. This formation has a thickness of approximately 3,500 feet throughout the Kreyenhagen Hills, of which about 2,700 is below and 800 above the upper *Mulinia* zone. On Anticline Ridge the formation has a thickness, only roughly measurable, of about 1,700 feet. In the Kettleman Hills, inasmuch as the base is not certainly exposed, the whole formation can not be measured. The maximum thickness exposed is about 3,000 feet in the south-central part of the hills along that part of the anticline where it plunges in both directions. Fossil beds are there exposed which may be close to the base of the formation. If they are, the whole formation is thinner than in the Kreyenhagen Hills. In other parts of the Kettleman Hills, where the lowest beds exposed are considerably above the base, the only means of determining the comparative thickness of the formation here and elsewhere is to compare the thickness from the summit down to the upper *Mulinia* zone, which has been correlated with a similar zone in the Kreyenhagen Hills. This thickness is about 1,900 to 2,000 feet in the northern part of the Kettleman Hills, but increases to 2,300 or 2,400, if not more, in the southern half, on the southwest flank of the anticline. Here again, therefore, there is indicated a thinning of the formation in the Kettleman Hills, as compared with the Kreyenhagen Hills, and this gradual decrease appears to continue on the northeastern side of the Kettleman Hills. On the other hand, there is a very decided thickening southeastward from Anticline Ridge along the anticline. In conclusion, all that may be said is that the Etchegoin is at least 2,000 feet and probably more nearly 2,500 feet thick in the northern part of the Kettleman Hills and at least 3,000 feet thick in the southern part. The thickness of it that must be pierced along the axis of the anticline in order to reach the underlying Jacalitos decreases gradually southward toward the central portion of the hills. At the south side of sec. 34, T. 21 S., R. 17 E., the upper *Mulinia* zone arches over the anticline and plunges northwestward beneath higher beds. At this point the beds are practically horizontal on the very axis of the fold and the depth to the top of the Jacalitos is probably only a few hundred feet, possibly in the neighborhood of 500 feet. From there southeastward to sec. 1, T. 23 S., R. 18 E., the thickening of the formation is more than offset by the plunge of the anticline in the opposite direction, and the depth to the Jacalitos gradually decreases. Thence southward the depth is probably nowhere more than a few hundred feet and is in general less than in the northern part of the hills.

The Jacalitos formation has a thickness similar to that of the Etchegoin both in the Kreyenhagen Hills and the Coalinga field. The question of the accessibility of the oil sand in the Kettleman Hills hinges in large measure on the question whether this similarity in thickness between the two formations holds good there. Does the Jacalitos become thinner eastward from the Kreyenhagen Hills, as the Etchegoin seems to do? It is very probable that it does.

The Santa Margarita increases in thickness from Zapato Creek to Dagany Gap from about 200 feet to over 1,000 feet. It probably underlies the Kettleman Hills with some such thickness and with a probable similar thickening southward. There is no way of telling whether it thickens or thins eastward from the Kreyenhagen Hills, and it may therefore be assumed as constant.

On the basis of the probable conditions outlined above the combined thickness of the lower part of the Etchegoin below the upper *Mulinia* zone and of the Jacalitos and Santa Margarita formations may be arbitrarily assumed to be 3,500 feet in the northern part of the Kettleman Hills and 4,500 in the south-central part. The lines on the map over the Kettleman Hills showing the possible limits of the productive territory are drawn on the basis of such an assumption.

These figures are moderate estimates and the chances are small that the thicknesses are less than this. It must be borne in mind, however, that they are at best only guesses based on a balance of probabilities. If these figures be true it means that the top of the Vaqueros formation, the supposed oil sand, lies between 3,500 and 4,000 feet immediately below the axis of the anticline throughout the hills southeast of the Big Tar Canyon-Lemoore road. Away from the axis on either side the beds begin to dip away and the depth to the Vaqueros increases rapidly. The lines bounding the supposed oil territory represent the limits of the area in which the top of the Vaqueros would be reached within 4,500 feet vertically down if the above-assumed thicknesses were correct. On the other hand, if the formations are as thick as they are in the Kreyenhagen Hills, the top of the Vaqueros would be considerably below 4,500 feet even along the axis of the anticline. In the southern part of the Kettleman Hills, for a few miles north of Avenal Gap and in the group south of there, the structure is poorly displayed. Little definite information has been obtained further than that the horizon exposed along the axis is in the lower portion of the Etchegoin. Owing to the removal of the Eocene by faulting near Little Tar Canyon and south of there it is possible that the Tejon is not present beneath the southern portion of the Kettleman Hills.

No surface indications of oil are known to exist in the Kettleman Hills, but it is not likely that oil would have been allowed to escape through the great thickness of overlying beds forming the regularly arching anticline. It is supposed, also, that the oil is retained by the overarching shale of the Santa Margarita. Indications suggesting petroleum have been observed in the Lost Hills several miles south of the south end of the Kettleman Hills. The Lost Hills may be due to an extension of the Coalinga anticline southward, and it is possible that the fold plunges northward and exposes a low portion of the series into which the oil has had access.

In conclusion, it may be said that the Kettleman Hills offer a fair chance for the discovery of oil at a depth of from 3,000 to 4,500 feet along the axis of the anticline, and that the conditions favor a well-preserved supply. The only possible means of gaining any definite knowledge of the oil-bearing formations beneath these hills is by drilling. In order to test the possibilities of the region satisfactorily wells should be sunk immediately on the axis of the anticline. The most favorable location for a test well would probably be between the Big Tar Canyon-Lemoore road and a point 13 miles southeast of the northwest end of the hills.

PRODUCTION.

The following table of production of the Coalinga district by calendar years from 1897 to 1907 was compiled by Miss Belle Hill, under the direction of Dr. David T. Day, of the Geological Survey. The production for 1908 will probably be about 12,000,000 barrels, which, with the greatly increased price (63 to 75 cents per barrel), will bring the value of the product for the year close to $8,000,000.

Production of Coalinga district, 1897 to 1907.

[In barrels of 42 gallons each.]

Year.	Production.	Value.	Year.	Production.	Value.
1897	70,140		1903	2,138,058	$705,559
1898	154,000		1904	5,114,958	1,520,847
1899	439,372		1905	10,967,015	2,657,009
1900	532,000	$532,000	1906	7,991,039	1,848,300
1901	780,650	390,325	1907	8,871,723	3,091,934
1902	572,498	257,629			

By a rough estimate based on the data in the hands of the writers, the amount of available oil contained before exploitation began in that part of the Coalinga district shown on the contour map (Pl. II) was 2,875,000,000 barrels of 42 gallons each. Of this amount about 2,000,000,000 barrels was contained in the territory west of the Coalinga syncline and 875,000,000 barrels east of the syncline. The total amount taken from the ground up to the present time, including an estimated production of 12,000,000 barrels for 1908, approaches 50,000,000 barrels, which, when subtracted from the estimated total, leaves 2,825,000,000 barrels available after 1908. At the present rate of production this supply would last over 200 years, but with the rapid rate at which the increase in production is now taking place the time during which the supply will hold out promises to be far less. Moreover, it is not possible to state what percentage of the oil present can ultimately be obtained.

The estimate is, of course, merely an approximation. It was arrived at by assuming a 10 per cent impregnation of the oil sands and calculating from all the data available the probable thickness of sand under each quarter section.

TRANSPORTATION FACILITIES.

One railroad and two pipe lines comprise the transportation facilities for the oil produced in the Coalinga district.

A branch of the Southern Pacific Railroad joins Coalinga with the main lines at Hanford and Goshen Junction, and also with the main lines of the Atchison, Topeka and Santa Fe Railway at Hanford and Visalia. The storage tanks and loading racks for the district are at Ora station, 1½ miles northeast of Coalinga.

A 6-inch pipe line of the Coalinga Oil Transportation Company, a subsidiary of the Associated Oil Company, joins Coalinga with the seaboard at Monterey, 110 miles northwest. This line was first constructed in 1904 as an independent project, and was generally known, from the name of its projector, as the Matson pipe line. The route traversed is along Alcalde Canyon, Waltham Valley, Priest Valley, Lewis Creek, and the Salinas Valley. Several pumping stations are situated along the line between Coalinga and Monterey, the main pumping station being located in the SW. ¼ sec. 18, T. 20 S., R. 15 E.; it is joined by minor lines with various parts of the Eastside and Westside fields.

An 8-inch branch pipe line, 28 miles long, joins the Coalinga field with the main Kern River-Point Richmond line of the Standard Oil Company at Mendota. The total distance from Coalinga to tidewater by this line is 198 miles. The main pumping station of this company for the Coalinga field is in the NW. ¼ sec. 36, T. 19 S., R. 15 E.

Numerous local lines transport the oil from various parts of the field to the shipping stations. Among these lines are those of the Union Oil Company from sec. 13, T. 20 S., R. 14 E., to Ora; the California Oilfields, Ltd., from the Eastside field to Ora; the Coalinga Oil Company, from the Oil City field to Ora; Westside line, from the Westside field to Ora, and the Associated Oil Company, from the Westside field to Ora.

MINERAL LANDS.

The following areas within the Coalinga district have been classified as mineral lands, and such of these as yet belong to the Government have been withdrawn from any but mineral-land entry. The lands classified as mineral include all those lying between the outcrop of the lowest oil-bearing formations, the Tejon (Eocene), and a line marking the limits of the area in which the uppermost productive oil zone (zone B), can be reached by a well less than 4,500 feet in depth. (See pp. 113–114 for relative probability of productiveness of these lands.)

List of mineral lands in Coalinga district.

T. 18 S., R. 15 E.:
  W. ½ and SE. ¼ sec. 36, secs. 35, 34, and 33.
T. 19 S., R. 14 E.:
  S. ½ and NE. ¼ sec. 25, S. ½ sec. 35, and sec. 36.
T. 19 S., R. 15 E.:
  Secs. 1 to 4, 8 to 17, SE. ¼ sec. 18, and secs. 19 to 36 except NW. ¼ sec. 19.
T. 19 S., R. 16 E.:
  W. ½ secs. 7, 18, 19, and 30, and all of sec. 31.
T. 20 S., R. 14 E.:
  Secs. 1 to 3, 10 to 15, 22 to 26, 35, and 36.
T. 20 S., R. 15 E.:
  All of township except secs. 23, 26, 35, 36, SW. ¼ sec. 14, E. ½ sec. 27, N. ½ and NE. ¼ sec. 25.
T. 20 S., R. 16 E.:
  W. ½ sec. 5, secs. 6, 7, 8, SW. ¼ sec. 9, secs. 16 to 21, W. ½ sec. 22, secs. 27 to 30, NE. ¼ sec. 31, secs. 32 to 33, and W. ½ sec. 34.

T. 21 S., R. 14 E.:
Sec. 1, E. ½ sec. 2, sec. 12, N. ½ and SE. ¼ sec. 13.

T. 21 S., R. 15 E.:
Secs. 2 to 9, N. ½ sec. 10, NW. ¼ sec. 11, S. ½ sec. 16, secs. 17, 18, 21, 22, NW. ¼ and S. ½ sec. 23, secs. 26, 27, E. ½ sec. 28, N. ½ and SE. ¼ sec. 34, and W. ½ sec. 35.

T. 21 S., R. 16 E.:
N. ½ sec. 3 and NE. ¼ sec. 4.

T. 21 S., R. 17 E.:
Secs. 33, 34, and NW. ¼ and S. ½ sec. 35.

T. 22 S., R. 15 E.:
SW. ¼ sec. 5, S. ½ sec. 6, secs. 7, 8, NW. ¼ and S. ½ sec. 9, SW. ¼ sec. 10, SW. ¼ sec. 13, NW. ¼ and S. ½ sec. 14, secs. 15, 16, N. ½ sec. 17, N. ½ sec. 18, NW. ¼ sec. 22, NW. ¼ and E. ½ sec. 23, secs. 24, 25, and NE. ¼ sec. 26.

T. 22 S., R. 16 E.:
NW. ¼ and S. ½ sec. 19, SW. ¼ sec. 20, SW. ¼ sec. 27, NW. ¼ and S. ½ sec. 28, secs. 29, 30, N. ½ sec. 31, secs. 32 to 34, and SW. ¼ sec. 35.

T. 22 S., R. 17 E.:
NW. ¼ and S. ½ sec. 1, secs. 2, 3, E. ½ sec. 4, NW. ¼ and E. ½ sec. 10, secs. 11, 12, NW. ¼ and E. ½ sec. 13, and NE. ¼ sec. 14.

T. 22 S., R. 18 E.:
Sec. 7, NW. ¼ and S. ½ sec. 8, NW. ¼ and S. ½ sec. 16, secs. 17, 18, N. ½ sec. 19, secs. 20, 21, 22, SW. ¼ sec. 25, secs. 26, 27, 28, NE. ¼ sec. 29, NE. ¼ sec. 33, and secs. 34, 35, and 36.

T. 23 S., R. 16 E.:
S. ½ sec. 1, secs. 2, 3, 4, N. ½ sec. 10, secs. 11, 12, and N. ½ sec. 13.

T. 23 S., R. 17 E.:
Sec. 7, S. ½ sec. 8, SW. ¼ sec. 15, NW. ¼ and S. ½ sec. 16, sec. 17, NW. ¼ and E. ½ sec. 18, N. ½ sec. 20, secs. 21, 22, SW. ¼ sec. 23, SW. ¼ sec. 25, sec. 26, N. ½ and SE. ¼ sec. 27, NE. ¼ sec. 35, and sec. 36.

T. 23 S., R. 18 E.:
Secs. 1, 2, NE. ¼ sec. 3, E. ½ sec. 11, secs. 12, 13, N. ½ and SE. ¼ sec. 24, NE. ¼ sec. 25, and SW. ¼ sec. 31.

T. 23 S., R. 19 E.:
W. ½ sec. 6, secs. 7, 18, 19, W. ½ sec. 20, SW. ¼ sec. 28, secs. 29, 30, E. ½ sec. 31, secs. 32, 33, and SW. ¼ sec. 34.

T. 24 S., R. 18 E.:
SW. ¼ sec. 5, secs. 6, 7, NW. ¼ and S. ½ sec. 9, SW. ¼ sec. 15, sec. 16, N. ½ and SE. ¼ sec. 17, N. ½ and SE. ¼ sec. 21, NW. ¼ and S. ½ sec. 22, sec. 27, E. ½ sec. 28, sec. 34, and W. ½ sec. 35.

T. 24 S., R. 19 E.:
Secs. 3, 4, N. ½ and SE. ¼ sec. 5, secs. 9, 10, 15, 16, 21, 22, SW. ¼ sec. 26, secs. 27, 28, N. ½ and SE. ¼ sec. 33, sec. 34, and NW. ¼ and S. ½ sec. 35.

OIL COMPANIES AND OIL WELLS IN THE COALINGA DISTRICT.

The following is a practically complete list of all of the oil companies which have drilled or are drilling wells in the Coalinga district. The locations of the wells are indicated wherever known and the elevation of each well given in most instances, having been obtained by instrument survey by E. P. Davis, topographer. There are now 395 productive wells, 75 abandoned wells, and between 75 and 100 drilling wells in the district.

Oil companies and oil wells in Coalinga district.

[Location by Mount Diablo base and meridian.]

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Ætna. (See California Oilfields, Ltd.)				
Ajax		[a]1	SW. ¼ sec. 32, T. 19 S., R. 15 E.	
American Petroleum		[b]2	Sec. 30, T. 20 S., R. 15 E	
Angelus		1	NE. ¼ sec. 26, T. 20 S., R. 14 E.	840
Do		2	do	842
Arline. (See California Oilfields, Ltd.)				
Associated		1	SW. ¼ sec. 22, T. 19 S., R. 15 E.	1,255
Do		2	do	1,235
Do		3	do	1,223
Do		4	do	1,208
Do		5	do	1,144
Do	Sauer Dough No. 1	1	do	1,435
Do	Sauer Dough No. 2	2	do	1,304
Do	Sauer Dough No. 3	3	do	1,313
Do	Sauer Dough No. 4	4	do	1,388
Do	Sauer Dough No. 5	5	do	1,435
Do	Sauer Dough No. 6	6	do	1,283
Do	Sauer Dough No. 7	7	do	1,340
Do		1	SE. ¼ sec. 36, T. 20 S., R. 14 E.	835
Do		2	do	875
Do		3	do	831
Do		4	do	934
Do		5	do	828
Do		21	NE. ¼ sec. 36, T. 20 S., R. 14 E.	800
Do		23	do	814
Do		25	do	828
Do		27	NW. ¼ sec. 36, T. 20 S., R. 14 E.	843
Do		29	do	858
Avenal Land and Oil		[a]2	Sec. 18, T. 23 S., R. 17 E	
Avon. (See California Oilfields, Ltd.)				
B and B	Brix and Buntin	1	SE. ¼ sec. 12, T. 20 S., R. 14 E.	848
Do		2	do	852
Baby King		[a]1	NE. ¼ sec. 11, T. 23 S.. R. 16 E.	
Badger State		[a]1	Sec. 1, T. 21 S., R. 14 E	
Black Mountain		[a]2	NW. ¼ sec. 33, T. 22 S., R. 16 E.	
Blair		[b]1	NW. ¼ sec. 14, T. 21 S., R. 15 E.	
Blue Diamond		[a]1	NE. ¼ sec. 26, T. 20 S., R. 14 E.	920
Blue Goose		[a]1	NE. ¼ sec. 20, T. 19 S., R. 15 E.	
Bonanza King		[a]1	SW. ¼ sec. 10, T. 19 S., R. 15 E.	
Boston and California		[b]1	SE. ¼ sec. 24, T. 19 S., R. 15 E.	
Buena Vista (Kettleman Hills).				
Buntin. (See California Diamond.)				
Caledonian		1	NE. ¼ sec. 26, T. 20 S., R. 14 E.	882
Do		[a]2	do	880
Do		3	do	847
Do		4	do	842
California and New York		1	SE. ¼ sec. 12, T. 20 S., R. 14 E.	834
Do		2	do	848
Do		3	do	829
Do		4	do	835
Do		5	do	843
California Diamond		1	SW. ¼ sec. 12, T. 19 S., R. 15 E.	802
Do	Ellis, No. 1	3	NE. ¼ sec. 31, T. 19 S., R. 15 E.	1,192
Do		4	do	1,196
Do	Buntin, No. 1	[a]1	NW. ¼ sec. 24, T. 21 S., R. 15 E.	
California Monarch		1	SE. ¼ sec. 26, T. 19 S., R. 15 E.	954
Do		[b]2	do	889
California Oil and Gas		[a]1	SE. ¼ sec. 19, T. 19 S., R. 15 E.	
California Oilfields, Ltd	Avon, No. 1	1	SW. ¼ sec. 14, T. 19 S., R 15 E.	1,101
Do	Avon, No. 2	2	NW. ¼ sec. 14, T. 19 S., R. 15 E.	1,035
Do	Kaweah, No. 1	3	NE. ¼ sec. 14, T. 19 S., R. 15 E.	877
Do	Kaweah, No. 2	4	SE. ¼ sec. 14, T. 19 S., R. 15 E.	950
Do	Avon, No. 3	[b]5	NW. ¼ sec. 14, T. 19 S., R. 15 E.	856
Do		1	SE. ¼ sec. 21, T. 19 S., R. 15 E.	1,451
Do		2	do	1,322
Do		3	do	1,444
Do		4	do	1,340

[a] Abandoned.

[b] Drilling.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
California Oilfields, Ltd		5	SE. ¼ sec. 21, T. 19 S., R. 15 E.	1,429
Do		6	do	1,461
Do		7	do	1,377
Do		8	do	1,383
Do		9	NE. ¼ sec. 21, T. 19 S., R. 15 E.	1,368
Do	Arline, No. 1	1	SW. ¼ sec. 26, T. 19 S., R. 15 E.	1,007
Do	Arline, No. 2	2	NW. ¼ sec. 26, T. 19 S., R. 15 E.	1,028
Do	Northeastern, No. 1	3	NE. ¼ sec. 26, T. 19 S., R. 15 E.	956
Do		1	NW. ¼ sec. 27, T. 19 S., R. 15 E.	1,387
Do		2	do	1,363
Do		3	do	1,349
Do		4	do	1,353
Do		5	do	1,380
Do		6	do	1,214
Do		7	do	1,331
Do		8	do	1,305
Do		9	do	[a] 1,319
Do		10	do	[a] 1,080
Do		11	do	[a] 1,340
Do		12	SW. ¼ sec. 27, T. 19 S., R. 15 E.	[a] 1,284
Do		13	NW. ¼ sec. 27, T. 19 S., R. 15 E.	[a] 1,130
Do		14	do	[a] 1,270
Do		15	do	[a] 1,225
Do		16	do	[a] 1,229
Do		17	do	1,332
Do		18	do	1,340
Do		19	SW. ¼ sec. 27, T. 19 S., R. 15 E.	1,256
Do		20	do	1,307
Do		21	do	1,117
Do		22	do	1,144
Do		23	SE. ¼ sec. 27, T. 19 S., R. 15 E.	1,105
Do		24	SW. ¼ sec. 27. T. 19 S., R. 15 E.	1,238
Do		25	do	1,246
Do		26	NW. ¼ sec. 27, T. 19 S., R. 15 E.	1,273
Do		[b] 27	SE. ¼ sec. 27, T. 19 S., R. 15 E.	983
Do		28	NW. ¼ sec. 27, T. 19 S., R. 15 E.	1,257
Do		29	do	1,188
Do		30	do	[a] 1,275
Do		31	SW ¼ sec. 27, T. 19 S., R. 15 E.	1,194
Do		32	do	1,166
Do		33	do	1,260
Do		[b] 34	NE. ¼ sec. 27, T. 19 S., R. 15 E.	1,022
Do		35	NW. ¼ sec. 27, T. 19 S., R. 15 E.	1,168
Do		36	NE. ¼ sec. 27. T. 19 S., R. 15 E.	[a] 1,180
Do		37	SW. ¼ sec. 27, T. 19 S., R. 15 E.	1,271
Do		38	do	1,234
Do		39	do	1,225
Do		41	NW. ¼ sec. 27, T. 19 S., R. 15 E.	[a] 1,350
Do		1	SW. ¼ sec. 29, T. 19 S., R. 15 E.	1,217
Do		2	do	1,256
Do	Ætna, No. 1	1	SE. ¼ sec. 30, T. 19 S., R. 15 E.	1,225
Do	Westmoreland, No. 1.	1	NW. ¼ sec. 34, T. 19 S., R. 15 E.	1,118
Do	Forty, No 1	2	NE. ¼ sec. 34, T. 19 S., R. 15 E.	1,096
Do	Westmoreland, No. 2.	3	NW. ¼ sec. 34, T. 19 S., R. 15 E.	1,109
Do	Missouri Coalinga, No. 1.	4	do	1,150
Do	Westmoreland, No. 3.	5	do	1,085
Do	Forty, No. 3	6	NE. ¼ sec. 34, T. 19 S., R. 15 E.	1,061
Do	Pittsburg - Coalinga, No. 1.	7	do	1,080
Call		1	NW. ¼ sec. 32, T. 19 S., R. 15 E.	1,213
Caribou Oil Mining		1	SW. ¼ sec. 22, T. 19 S., R. 15 E.	1,399
Do		2	do	1,356
Do		3	do	1,357
Do		4	do	1,417
Do		5	do	1,391
Do		6	do	1,400
Do		7	do	1,297
Do		8	do	1,234
Do		9	do	1,204
Do		10	do	1,233
Do		11	do	1,313
Do		12	do	1,116
Do		[b] 13	do	1,309
Carmelita		[c] 1	SE. ¼ sec. 3, T. 20 S., R. 15 E.	
Circle		[b] 1	NE. ¼ sec. 35, T. 20 S., R. 14 E.	
Claremont		1	NW. ¼ sec. 24, T. 20 S., R. 14 E.	[a] 810
Do		2	do	[a] 814

[a] Approximate. [b] Drilling. [c] Abandoned.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Claremont		3	NW. ¼ sec. 24, T. 20 S., R. 14 E.	[a] 805
Do		4	do	792
Do		[b] 1	NE. ¼ sec. 4, T. 20 S., R. 15 E.	1,022
Coalinga	Producers and Consumers, No. 1.	[c] 1	NW. ¼ sec. 20, T. 19 S., R. 15 E.	[a] 1,405
Do		2	do	1,453
Do	Producers and Consumers, No. 2.	[c] 2	do	[a] 1,410
Do		3	do	1,453
Do	Producers and Consumers, No. 3.	3	do	1,421
Do		4	do	1,449
Do		5	do	1,465
Do		6	do	1,435
Do		7	do	1,579
Do		9	do	1,499
Coalinga Four			Sec. 4, T. 20 S., R. 15 E	
Coalinga Mohawk		[b] 1	NW. ¼ sec. 12, T. 20 S., R. 15 E.	[a] 850
Coalinga Pacific		1	NW. ¼ sec. 7, T. 20 S., R. 15 E.	880
Do		2	do	883
Do		3	do	910
Do		4	do	873
Coalinga-Peerless		1	NW. ¼ sec. 22, T. 19 S., R. 15 E.	1,362
Do		2	do	1,284
Do		3	do	1,363
Do		4	do	1,360
Do		5	do	1,260
Do		6	do	1,259
Do		7	do	1,261
Do		8	do	1,212
Do		9	do	1,224
Do		10	do	1,168
Do		11	do	1,259
Do		12	do	1,150
Coalinga Petroleum		1	NE. ¼ sec. 14, T. 20 S., R. 14 E.	870
Do		2	do	878
Do		3	do	887
Do		4	do	883
Coalinga Southern		[b] 1	NW. ¼ sec. 6, T. 21 S., R. 15 E.	920
Coalinga Western		1	NE. ¼ sec. 23, T. 20 S., R. 14 E.	968
Do		2	do	977
Do		3	do	960
Do		4	do	910
Do		5	do	887
Do		(?)6	do	960
Do		(?)7	do	869
Coast Range		1	SW. ¼ sec. 17, T. 19 S., R. 15 E.	[a] 1,450
Do		2	do	[a] 1,450
Do		3	do	1,451
Do		4	SE. ¼ sec. 17, T. 19 S., R. 15 E.	1,469
Do		5	SW. ¼ sec. 17, T. 19 S., R. 15 E.	1,485
Do		6	do	1,533
Commercial		[c] 2	SE. ¼ sec. 12, T. 21 S., R. 14 E.	
Commercial Petroleum		1	do	869
Do		1	NE. ¼ sec. 31, T. 19 S., R. 15 E.	1,236
Do		2	do	1,243
Do		3	do	1,242
Do		4	do	1,253
Do		5	do	1,244
Do		6	do	1,241
Do		7	do	1,259
Do		8	do	1,254
Do		9	do	1,239
Do		10	do	1,220
Confidence		2	NW. ¼ sec. 31, T. 19 S., R. 15 E.	[a] 1,280
Do		4	do	[a] 1,275
Do		5	SW. ¼ sec. 31, T. 19 S., R. 15 E.	1,101
Do		6	NW. ¼ sec. 31, T. 19 S., R. 15 E.	1,240
Do		7	do	1,236
Do		8	SW. ¼ sec. 31, T. 19 S., R. 15 E.	1,251
Do		9	do	1,190
Do		10	do	1,227
Do		11	do	1,171
Do	K and C, No. 5	12	do	1,203
Do		[b] 13	do	1,205
Do		[b] 14	do	1,243
Consolidated Oil and Development.		[c] 1	NE. ¼ sec. 10, T. 23 S., R. 16 E.	

[a] Approximate.

[b] Drilling.

[c] Abandoned.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Crescent		[a] 1	SE. $\frac{1}{4}$ sec. 20, T. 19 S., R. 15 E.	
Cypress	R. H. Herron, No. 1	1	SE. $\frac{1}{4}$ sec. 1, T. 20 S., R. 14 E.	917
Do	R. H. Herron, No. 2	2	do	911
Do	R. H. Herron, No. 3	3	do	941
Do	R. H. Herron, No. 4	4	do	738
Domengine			NE. $\frac{1}{4}$ sec. 35, T. 18 S., R. 15 E.	
El Capitan (now Kern Trading and Oil).		2	NW. $\frac{1}{4}$ sec. 31, T. 19 S., R. 15 E.	
El Cerrito		[b] 1	NW. $\frac{1}{4}$ sec. 14, T. 23 S., R. 17 E.	
Elk		[a] 1	NE. $\frac{1}{4}$ sec. 22, T. 19 S., R. 15 E.	
Ellis. (See California Diamond.)				
Esperanza Oil and Gas		1	SW. $\frac{1}{4}$ sec. 6, T. 20 S., R. 15 E.	997
Do		2	do	989
Do		3	do	972
Do		4	do	956
Do		5	do	981
Do		6	do	943
Do		[b] 7	do	936
Do		8	do	916
Do		[a] 2	SW. $\frac{1}{4}$ sec. 14, T. 22 S., R. 17 E.	
Esperanza Land and Oil		[b] 1	Sec. 30, T. 21 S., R. 15 E.	
Euclid		1	SW. $\frac{1}{4}$ sec. 24, T. 20 S., R. 14 E.	814
Do		2	do	824
Fauna		[a] 1	NW. $\frac{1}{4}$ sec. 28, T. 19 S., R. 15 E.	
Florence		[a] 2	NW. $\frac{1}{4}$ sec. 15, T. 22 S., R. 17 E.	
Forty. (See California Oilfield, Ltd.)				
Fresno-San Francisco		1	NE. $\frac{1}{4}$ sec. 1, T. 20 S., R. 14 E.	1,140
Do		2	do	1,128
Do		3	do	1,072
Do		4	do	1,114
Gibbs		[a] 1	NW. $\frac{1}{4}$ sec. 28, T. 21 S., R. 17 E.	
Golden Crest	Kreyenhagen, No. 1	[b] 1	NE. $\frac{1}{4}$ sec. 12, T. 22 S., R. 15 E.	
Golden State (now California Oilfields, Ltd.).		[a] 1	SE. $\frac{1}{4}$ sec. 30, T. 19 S., R. 15 E.	
Graham, W. M.		1	NE. $\frac{1}{4}$ sec. 6, T. 21 S., R. 15 E.	759
Do		1	Sec. 2, T. 19 S., R. 15 E.	
Great Western		[a] 1	SW. $\frac{1}{4}$ sec. 26, T. 19 S., R. 15 E.	
Guthrey		1	NE. $\frac{1}{4}$ sec. 31, T. 19 S., R. 15 E.	1,267
Do		2	do	1,263
Do		3	do	1,227
Do		4	do	1,242
Guthrey. (See Yellowstone.)				
Hanford		1	NW. $\frac{1}{4}$ sec. 28, T. 19 S., R. 15 E.	1,356
Do		2	do	1,379
Do		3	do	1,404
Do		4	do	1,385
Do		5	SW. $\frac{1}{4}$ sec. 28, T. 19 S., R. 15 E.	1,376
Do		6	NW. $\frac{1}{4}$ sec. 28, T. 19 S., R. 15 E.	1,387
Do		7	do	1,469
Do		8	SW. $\frac{1}{4}$ sec. 28, T. 19 S., R. 15 E.	1,341
Hawkeye State		[a] 2	Sec. 6, T. 21? S., 15? E.	
Henshaw. (See Sunnyside.)				
Herron, R. H. (See Cypress.)				
Highland	New York, Nos. 1 and 2.	[a] 2	SW. $\frac{1}{4}$ sec. 20, T. 19 S., R. 15 E.	
Home		1	NE. $\frac{1}{4}$ sec. 20, T. 19 S., R. 15 E.	[c] 1,490
Do		2	do	1,491
Do		3	do	1,567
Do		4	do	1,528
Do		5	do	1,597
Do		6	do	1,519
Do		7	do	1,585
Do		8	do	1,593
Inca		1	NW. $\frac{1}{4}$ sec. 24, T. 20 S., R. 14 E.	801
Do		2	do	811
Do		3	do	816
Do		4	do	799
Do		5	do	814
Do		6	do	805
Do		7	do	797
Do		8	do	805
Do		9	do	814
Do		10	do	818
Do		11	do	834
Do		12	do	870
Imperial		[b] 1	Sec. 2, T. 19 S., R. 15 E.	

[a] Abandoned. [b] Drilling. [c] Approximate.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level. Feet.
Independence. (See Standard.)				
Independent		[a] 1	NE. ¼ sec. 17, T. 19 S., R. 15 E.	
Investment		[a] 1	SE. ¼ sec. 16, T. 19 S., R. 15 E.	
Iowa		[a] 1	SW. ¼ sec. 4, T. 22 S., R. 17 E.	
Jacalitos		[b] 1	Sec. 30, T. 21 S., R. 15 E.	
K. and C. (See Confidence.)				
Kaweah. (See California Oilfields, Ltd.)				
Kern Trading and Oil		[b] 1	NW. ¼ sec. 35, T. 19 S., R. 15 E.	
Do		1	SW. ¼ sec. 31, T. 19 S., R. 15 E.	[c] 1,210
Do		2	do	1,234
Do		3	NW. ¼ sec. 31, T. 19 S., R. 15 E.	1,222
Do		7	do	1,270
Do		8	do	1,242
Do		1	SW. ¼ sec. 25, T. 20 S., R. 14 E.	811
Do		2	do	803
Keystone		[a] 1	NW. ¼ sec. 32, T. 19 S., R. 15 E.	
Kings County		[a] 1	NE. ¼ sec. 3, T. 23 S., R. 16 E.	
Do		[a] 1	SW. ¼ sec. 3, T. 23 S., R. 16 E.	
Kreyenhagen		[a] 2	SE. ¼ sec. 32, T. 22 S., R. 16 E.	
Kreyenhagen. (See Golden Crest.)				
Lorene		[b] 1	NW. ¼ sec. 12, T. 19 S., R. 15 E.	[c] 825
Lucile		1	NE. ¼ sec. 6, T. 21 S., R. 15 E.	770
Do		2	do	761
McCreary. (See California Oilfields, Ltd.)				
Maine State		1	NE. ¼ sec. 31, T. 19 S., R. 15 E.	1,256
Do		[a] 2	do	[c] 1,300
Do		3	do	1,274
Do		4	do	1,237
Do		5	do	[c] 1,250
Do		6	SE. ¼ sec. 31, T. 19 S., R. 15 E.	1,089
Do		7	do	1,119
Do		8	do	1,119
Do		9	do	1,154
Manchester		[a] 1	SW. ¼ sec. 18, T. 21 S., R. 15 E.	900
Marengo		1	SW. ¼ sec. 24, T. 20 S., R. 14 E.	[c] 790
Do		2	do	[c] 800
Do		3	do	[c] 795
Do		[b] 4	do	[c] 795
May Brothers		[a] 1	SE. ¼ sec. 14, T. 20 S., R. 14 E.	
Mercantile Crude		1	NW. ¼ sec. 6, T. 20 S., R. 15 E.	1,097
Do		2	do	[c] 1,120
Do		3	do	1,006
Do		4	do	1,002
Michigan Oil and Development.		[b] 1	Sec. 17?, T. 19 S., R. 13 E.	
Minnesota (now Southern Pacific R. R.)		[a] 2	NE. ¼ sec. 33, T. 19 S., R. 15 E.	
Missouri-Coalinga. (See California Oilfields, Ltd.)				
M., K. and T		1	SW. ¼ sec. 8, T. 20 S., R. 15 E.	868
Do		[b] 2	do	866
Montjack		[a] 1	NW. ¼ sec. 22, T. 19 S., R. 15 E.	
Mount Hamilton Land and Oil.		[a] 1	SE. ¼ sec. 14, T. 21 S., R. 14 E.	1,002
Mutual		[a] 1	SE. ¼ sec. 20, T. 19 S., R. 15 E.	
Nathan. (See Porter & Scribner.)				
New Era		1	SE. ¼ sec. 12, T. 20 S., R. 14 E.	
New Home		1	SE. ¼ sec. 14, T. 20 S., R. 14 E.	736
Do		2	do	746
Do		3	do	737
New San Francisco Crude		1	NW. ¼ sec. 6, T. 20 S., R. 15 E.	1,135
Do		2	do	1,105
Do		3	do	1,068
Do		4	do	1,098
Do		5	do	1,079
New York. (See Highland.)				
Norse		1	SW. ¼ sec. 24, T. 20 S., R. 14 E.	
Do		[b] 2	do	
Do		[b] 3	do	
Do		4	do	
Northeastern. (See California Oilfields, Ltd.)				

[a] Abandoned. [b] Drilling. [c] Approximate.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Oceanic		[a]1	NW. ¼ sec. 1, T. 22 S., R. 17 E.	
Octave		1	NE. ¼ sec. 22, T. 19 S., R. 15 E.	1,212
Do		2	do	1,208
Oil City Petroleum. (See Standard.)				
Old Keystone		[a]1	SE. ¼ sec. 8, T. 19 S., R. 15 E.	
Oyama. (See California Oilfields, Ltd.)				
Ozark		1	NE. ¼ sec. 26, T. 20 S., R. 14 E.	[b]850
Do		2	do	[b]845
Peerless Consolidated		[c]1	NE. sec. 10, T. 20 S., R. 15 E.	815
Piedmont		[c]1	Sec. 24, T. 20 S., R. 14 E.	
Pennsylvania Coalinga		1	NE. ¼ sec. 24, T. 20 S., R. 14 E.	1,056
Do		2	SE. ¼ sec. 24, T. 20 S., R. 14 E.	976
Do		3	do	923
Do		4	do	975
Philadelphia and San Francisco.		1	SE. ¼ sec. 36, T. 19 S., R. 14 E.	1,121
Do		2	do	
Do		3	do	1,107
Phoenix		[a]3	SE. ¼ sec. 20, T. 19 S., R. 15 E.	
Pilot		1	SW. ¼ sec. 12, T. 20 S., R. 14 E.	
Pittsburg		1	SW. ¼ sec. 24, T. 19 S., R. 15 E.	830
Pittsburg-Coalinga. (See California Oilfields, Ltd.)				
Porter & Scribner	Nathan lease	1	NW. ¼ sec. 7, T. 20 S., R. 15 E.	873
Do	do	[a]2	do	868
Do	do	3	do	848
Premier		1	SE. ¼ sec. 24, T. 20 S., R. 14 E.	[b]790
Do		2	do	
Producers and Consumers. (See Coalinga.)				
Record		1	SE. ¼ sec. 22, T. 19 S., R. 15 E.	1,189
Do		2	do	1,177
Riverside (near Alcalde).				
Roanoke		[a]1	SE. ¼ sec. 36, T. 19 S., R. 14 E.	
Rock		[a]1	SW. ¼ sec. 28, T. 19 S., R. 15 E.	
St. Clair		1	SW. ¼ sec. 12, T. 20 S., R. 14 E.	
St. Francis		[c]1	SW. ¼ sec. 6, T. 21 S., R. 15 E.	[b]940
St. Lawrence		[a]1	NE. ¼ sec. 12, T. 23 S., R. 16 E.	
St. Paul-Fresno		1	NE. ¼ sec. 23, T. 20 S., R. 14 E.	[b]950
Do		2	do	970
Do		3	do	920
Do		4	do	906
Do		5	do	910
Santa Clara		[a]1	SW. ¼ sec. 30, T. 19 S., R. 15 E.	
Sauer Dough. (See Associated.)				
Section Seven		1	NW. ¼ sec. 7, T. 20 S., R. 15 E.	911
Do		2	do	915
Do		3	do	916
Do		4	do	908
Do		[c]5	do	[b]880
Section Six		[c]1	NW. ¼ sec. 6, T. 21 S., R. 15 E.	842
Section Ten		[a]1	SW. ¼ sec. 10, T. 19 S., R. 15 E.	
Selma. (See Zenith.)				
Seneca		[c]1	NW. ¼ sec. 12, T. 20 S., R. 14 E.	
Shawmut		1	NE. ¼ sec. 12, T. 20 S., R. 14 E.	878
Do		2	do	882
Do		3	do	892
Do		4	do	[b]910
Do		5	do	879
Shreeve		1	NW. ¼ sec. 6, T. 21 S., R. 15 E.	853
Standard	Independence, No. 1	1	NE. ¼ sec. 28, T. 19 S., R. 15 E.	1,497
Do	Independence, No. 3	3	do	1,440
Do	Independence, No. 4	4	do	1,374
Do	Independence, No. 5	5	do	[b]1,450
Do	Independence, No. 6	6	do	1,444
Do	Independence, No. 7	7	do	1,458
Do	Independence, No. 8	8	do	1,484
Do	Independence, No. 9	9	do	1,536
Do	Independence, No. 10	10	do	1,538
Do	Oil City Petroleum, No. 1.	11	SE. ¼ sec. 28, T. 19 S., R. 15 E.	1,371
Do	Oil City Petroleum, No. 2.	12	do	1,404
Do	Oil City Petroleum, No. 3.	13	do	1,372

[a] Abandoned. [b] Approximate [c] Drilling.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Standard	Oil City Petroleum, No. 4.	14	SE. ¼ sec. 28, T. 19 S., R. 15 E.	1,376
Do	Oil City Petroleum, No. 5.	15	do	1,448
Do	Oil City Petroleum, No. 6.	16	do	1,373
Do	Oil City Petroleum, No. 7.	17	do	1,348
Do	Oil City Petroleum, No. 8.	18	do	1,340
Do	Oil City Petroleum, No. 9.	19	do	1,361
Do	Oil City Petroleum, No. 10.	20	do	1,321
Do	Oil City Petroleum, No. 11.	21	do	1,323
Do	Oil City Petroleum, No. 12.	22	do	1,262
Do	Oil City Petroleum, No. 13.	23	do	1,211
Do	Oil City Petroleum, No. 14.	24	do	1,253
Do	Oil City Petroleum, No. 15.	25	do	1,275
Do	Twenty-eight, No. 14.	26	NE. ¼ sec. 28, T. 19 S., R. 15 E.	1,314
Do	Twenty-eight, No. 13.	27	do	1,395
Do	Twenty-eight, No. 12.	28	do	1,385
Do	Twenty-eight, No. 10.	29	do	1,241
Do	Twenty-eight, No. 11.	30	do	1,378
Do	Twenty-eight, No. 9	31	do	1,420
Do	Twenty-eight, No. 8	32	do	1,402
Do	Twenty-eight, No. 6	33	do	1,256
Do	Twenty-eight, No. 5	34	do	1,342
Do	Twenty-eight, No. 4	35	do	1,342
Do	Twenty-eight, No. 1	36	do	[a] 1,380
Do	Twenty-eight, No. 3	37	do	1,364
Do	Twenty-eight, No. 2	38	do	1,428
Do	Twenty-eight, No. 7	39	do	1,421
Do	Twenty-eight, No. 15.	40	do	1,456
Do	Twenty-eight, No. 16.	41	do	1,505
Stanislaus		[b] 1	NW. ¼ sec. 4, T. 22 S., R. 17 E.	
Star		[b] 1	NW. ¼ sec. 34, T. 19 S., R. 15 E.	
Stockholders		1	NE. ¼ sec. 28, T. 19 S., R. 15 E.	1,486
Do		2	do	1,385
Do		3	do	1,394
Do		4	do	1,407
Do		5	do	1,454
Stockton		[b] 2	NW. ¼ sec. 30, T. 22 S., R. 18 E.	
Sunnyside	Henshaw	[c] 1	SE. ¼ sec. 35, T. 20 S., R. 14 E.	
S. W. and B		1	NW. ¼ sec. 6, T. 20 S., R. 15 E.	1,061
Do		2	do	1,038
Do		3	do	1,031
Do		4	do	982
Tavern		[d] 1	Sec. 34, T. 18 S., R. 15 E.	
T. C		1	SW. ¼ sec. 2, T. 19 S., R. 15 E.	958
Traders		1	SW. ¼ sec. 24, T. 20 S., R. 14 E.	810
Do		2	do	818
Do		3	do	845
Do		4	do	833
Do		5	do	[a] 843
Twenty-eight. (See Standard.)				
Twenty-two		1	SE. ¼ sec. 22, T. 19 S., R. 15 E.	1,143
Turner		[d] 1	SW. ¼ sec. 2, T. 20 S., R. 15 E.	[a] 1,075
Do		[d] 2	do	[a] 975
Union		1	NW. ¼ sec. 13, T. 20 S., R. 14 E.	812
Do		2	NE. ¼ sec. 13, T. 20 S., R. 14 E.	811
Do		3	do	810
Do		4	NW. ¼ sec. 13, T. 20 S., R. 14 E.	817
Do		5	do	808
Do		6	do	824
Do		7	do	817
Do		8	do	837
Do		9	do	835
Venus		[b] 1	NW. ¼ sec. 5, T. 22 S., R. 14 E.	

[a] Approximate. [b] Abandoned. [c] Water well. [d] Drilling.

Oil companies and oil wells in Coalinga district—Continued.

Name of oil company.	Name of well.	No. of well.	Location.	Elevation above mean sea level.
				Feet.
Wabash		1	NE. ¼ sec. 24, T. 20 S., R. 14 E.	806
Do		2	do	802
Do		3	do	798
Do		4	do	793
Do		5	do	789
Do		6	do	787
Do		7	do	782
Do		8	do	796
Do		9	do	783
Do		10	do	779
Do		11	do	777
Do		12	do	775
Ward		1	NW. ¼ sec. 12, T. 20 S., R. 14 E.	933
Do		2	do	934
West Coalinga (water)		1	NE. ¼ sec. 12, T. 21 S., R. 14 E.	1,052
Westlake-Rommel		[a] 3	NE. ¼ sec. 2, T. 21 S., R. 14 E.	
Westmoreland. (See California Oilfields, Ltd.)				
Whale	King	[a] 1	Sec. 4, T. 22 S., R. 14 E.	
Whittier and Green		[a] 1	NW. ¼ sec. 26, T. 20 S., R. 14 E.	
Wisconsin		[a] 1	NE. ¼ sec. 32, T. 19 S., R. 15 E.	
W. K.		1	NW. ¼ sec. 2, T. 20 S., R. 15 E.	920
Do		2	do	1,125
Do		[b] 3	NE. ¼ sec. 2, T. 20 S., R. 15 E.	[c] 960
Wright Association		[a] 1	NW. ¼ sec. 26, T. 20 S., R. 14 E.	
Yellowstone	Guthrey, No. 1	1	NW. ¼ sec. 6, T. 21 S., R. 15 E.	917
York Coalinga		1	NW. ¼ sec. 6, T. 20 S., R. 15 E.	1,123
Do		2	do	1,085
Zenith	Selma, Nos. 1 and 2	[a] 2	SE. ¼ sec. 20, T. 19 S., R. 15 E.	
Zier		1	SW. ¼ sec. 1, T. 20 S., R. 14 E.	939
Do		2	do	938
Do		3	do	964
Do		4	do	970
Do		5	do	945
Do		6	do	939
Do		7	do	953

[a] Abandoned. [b] Drilling. [c] Approximate.

SURVEY PUBLICATIONS ON PETROLEUM AND NATURAL GAS.

The following list includes the more important papers relative to oil and gas published by the United States Geological Survey or by members of its staff. Those to which a price is affixed can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Any of the others (published by the Survey) can be had free by applying to the Director, U. S. Geological Survey, Washington, D. C.

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——— (See also Eldridge, G. H., and Arnold, R.)

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Clapp, F. G. The Nineveh and Gordon oil sands in western Greene County, Pa. In Bulletin No. 285, pp. 362–366. 1906.

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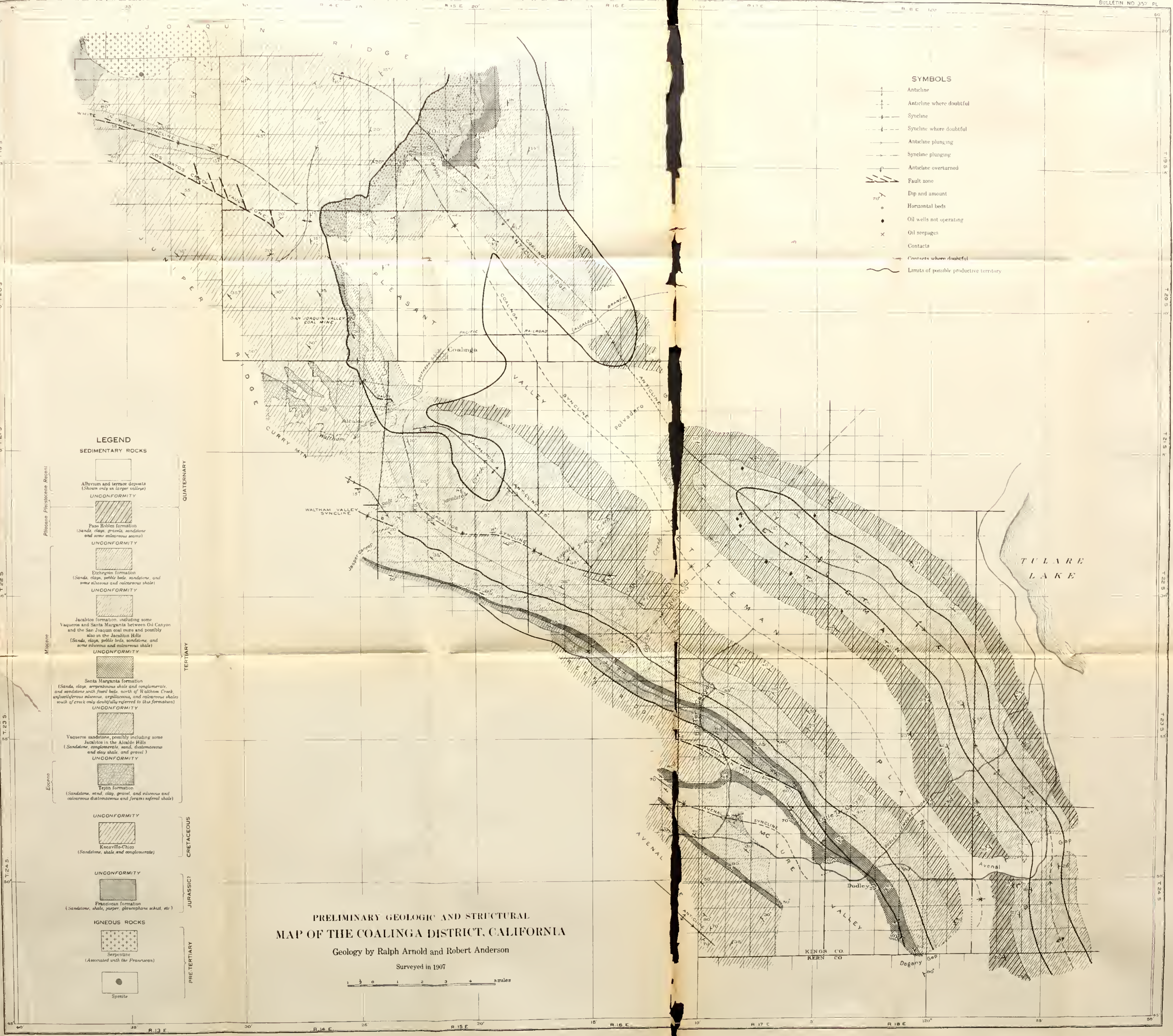

PRELIMINARY GEOLOGIC AND STRUCTURAL
MAP OF THE COALINGA DISTRICT, CALIFORNIA

Geology by Ralph Arnold and Robert Anderson

Surveyed in 1907

ANDREW B. GRAHAM CO. LITHOGRAPHERS WASHINGTON D.C.

STRUCTURAL CONTOUR MAP OF THE COALINGA FIELD

0 1 2 miles

Contour interval 100 feet
Datum is mean sea level
1908

Contours show distance above and below sea level of the top of oil zone B (*See explanation in text*)
The broken contour lines are hypothetical

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 358

GEOLOGY
OF THE
SEWARD PENINSULA TIN DEPOSITS
ALASKA

BY ADOLPH KNOPF

WASHINGTON
GOVERNMENT PRINTING OFFICE
1908

CONTENTS.

Economic geology—Continued.
Lodes—Continued.
Lost River—Continued.

ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

Since the discovery of stream tin in the York region by the Geological Survey in 1900 the tin deposits of this district have been discussed in several Survey publications. In all cases, however, the statements were based on investigations that were incidental to other work, and as this district had attracted much notice as a possible source of tin and considerable money had been spent in mining and prospecting, it appeared time, in the spring of 1907, to undertake a more thorough investigation.

To this task Mr. Knopf was assigned, with instructions to make a careful study of the mineral deposits and, so far as time permitted, to determine the laws of their occurrence and origin. It was thought best to emphasize the more purely scientific phase of the investigation, for the commercial phase can best be solved by the mining expert and engineer. Therefore, those who expect to find in this volume a statement of the commercial value of individual ore bodies will be disappointed. In the opinion of the writer, however, the presentation of the chief facts regarding the mineralogy and geology of the tin deposits, together with a careful analysis of these data, will have more value to the district as a whole than any attempt to publish a statement of commercial features of individual ore bodies. Moreover, it has become an established policy in the Alaskan work not to attempt to sample ore bodies, as such work is believed to fall outside of the province of the Federal geologist, and obviously without careful sampling the valuation of any given deposit is impossible.

The reader should not infer from the foregoing remarks that this paper is regarded as a final statement on the occurrence and genesis of the tin deposits. Difficulty of access, limited exposures, and lack of time prevented Mr. Knopf from making exhaustive studies. It is believed, however, that this report marks a great advance in the knowledge of the subject.

GEOLOGY OF THE SEWARD PENINSULA TIN DEPOSITS, ALASKA.[a]

By ADOLPH KNOPF.

INTRODUCTION.

Stream tin was discovered in the York region of Seward Peninsula during the fall of 1900 as a heavy and objectionable constituent which accumulated in the sluice boxes of the placer-gold prospectors. Some of this material was brought to Washington by A. H. Brooks, of the United States Geological Survey, who was engaged in a hasty reconnaissance of the mineral resources of the region, and was identified as cassiterite.[b] The discovery was soon heralded by the public press.

The true nature and value of the mineral once known, search was directed toward finding a wider distribution of the stanniferous gravels and toward locating the bed-rock source of the cassiterite. Two factors combined to stimulate this search—the failure of the gold placers of the region and the high market price of metallic tin in recent years. Ever since their discovery the Alaskan tin deposits, as they are popularly styled, have continued to attract considerable attention from the mining public—an interest due in large part to the fact that there are no producing tin mines in the United States proper.

Several reports of a preliminary character have been issued by the Geological Survey describing the geology and mineral resources of the York region, in which the chief deposits of tin occur. The presence of placer tin in Anikovik River and in its tributary, Buhner Creek, was first recorded by Brooks.[c] On the basis of a reconnaissance of the northwestern part of Seward Peninsula in 1901, Collier[d] was able to offer certain advice as to where search for lode tin might profitably be made. In 1903 he assisted a number of prospectors in making the original discovery of lode tin in Seward Peninsula and

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[a] A summary of the results given in this paper was published several months ago by Brooks, A. H., and others, in Mineral resources of Alaska; report on progress of investigations in 1907: Bull. U. S. Geol. Survey No. 345, 1908, pp. 251–267.

[b] Brooks, A. H., A new occurrence of cassiterite in Alaska: Science, new ser., vol. 13, No. 328, 1901, p. 593.

[c] Brooks, A. H., An occurrence of stream tin in the York region, Alaska: Mineral resources U. S. for 1900, U. S. Geol. Survey, 1901, p. 270. Also, A reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, Alaska, in 1900 (a special publication of the U. S. Geol. Survey), 1901, pp. 132–139.

[d] Collier, A. J., Prof. Paper U. S. Geol. Survey No. 2, 1902, p. 49.

was able to publish the first authentic information on the occurrence of cassiterite in place.[a] On returning from his examination of the Cape Lisburne coal fields in 1904, he spent a few days in the York region and noted the progress of development in opening up the tin deposits.[b] Later developments, in the fall of 1905, were fully described by Hess.[c]

No member of the Survey visited the region in 1906, but numerous popular reports indicated that extensive development work was in progress. Owing to the fact that the earlier investigations, which were incidental to field work in other parts of Seward Peninsula, were hampered by lack of time and by the inadequate development of the region, it was deemed advisable to give an entire field season to an examination of the tin deposits, including those of Ear Mountain, which had not been previously visited. With this purpose in view, the writer was instructed to examine all known occurrences of tin ore in Seward Peninsula, giving especial attention to the origin of the ores and the commercial importance of the field. Field work was commenced at Tin City on June 23, and ended at Teller on September 6, 1907.

Acknowledgments are due for the many courtesies extended to the writer while in the region, and it is an especial pleasure to thank Mr. John Vatney, of Ear Mountain, Mr. M. R. Luther, of Tin City, and Messrs. William C. Randt and S. Read, of Lost River, for their generous hospitality and substantial aid in furthering the field work. Thanks are also due Dr. W. T. Schaller, Dr. E. C. Sullivan, and Prof. E. F. Smith for assistance in chemical and mineralogical work.

PRODUCTION AND PROSPECTING.

The total production of tin ore in the entire region to the close of 1907 was about 160 tons of concentrates, all of which, except a few tons from lode deposits, came from the stream tin of Buck Creek.

The approximate annual value of the tin production of the York district since mining began is as follows:

Value of tin produced in York region, Alaska, 1902–1907.

1902	$8,000
1903	14,000
1904	8,000
1905	4,000
1906	38,640
1907	20,000
	92,640

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[a] Collier, A. J., Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 225, 1904. See also Bull. 229.

[b] Collier, A. J., Recent development of Alaska tin deposits: Bull. U. S. Geol. Survey No. 259, 1905, pp. 120–127.

[c] Hess, F. L., The York tin region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 145–157.

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Alfred H. Brooks, Geologist in charge
Topography by T. G. Gerdine
D. C. Witherspoon, and Alfred H. Brooks
Surveyed in 1900 1901

TOPOGRAPHIC RECONNAISSANCE MAP OF THE YORK TIN REGION, SEWARD PENINSULA, ALASKA

Scale $\frac{1}{250000}$

2 0 2 4 6 8 10 12 14 miles

2 0 2 4 6 8 10 12 16 kilometers

Contour interval 200 feet

At present four localities are being prospected for tin. They are included in an area of 400 square miles, about 100 miles northwest of the city of Nome, the supply point of the region. In geographic order from north to south these four localities are Ear Mountain, Buck Creek, Cape Mountain, and Lost River. Ear Mountain occupies an isolated position 40 miles north of the others, which are grouped together in the York region at the west end of the continent.

GEOGRAPHY OF THE REGION.

The region here to be considered comprises the extreme western projection of Seward Peninsula, or that portion of the American Continent which approaches nearest to Asia. On the northwest it is bounded by the Arctic Ocean, and on the southwest by Bering Sea—two bodies of water that are frozen over during seven months of the year. In 1907 navigation opened to Tin City, which is situated at the tip of the continent, on June 22, and a few days later the last of the ice had drifted northward through Bering Strait. During the open season gasoline schooners maintain a weekly service between Nome and points on Bering Sea, and a small passenger steamer, carrying the mail, calls every ten days while en route to Kotzebue Sound. A nominal ten-day mail service is thus afforded during the summer months, but a regular weekly service is obtained in the winter with sled and dog team.

The topographic character of the region is well brought out on the map (Pl. I). Toward the north the Arctic coastal plain forms a wide expanse of gently rolling topography with a relief of less than 50 feet, and so heavily grown over with moss as to be practically impassable to wagons. Numerous lakes dot the landscape, and the streams wind across the plain in tortuous courses, emptying into broad lagoons impounded behind barrier beaches. In the vicinity of Shishmaref Inlet the lower stretches of the streams are affected by the tidal ebb and flow.

Toward the south the York Mountains rise abruptly from the coastal plain. They are an exceedingly steep and rugged group, with an average altitude of 2,500 feet. Broad stream valleys, however, penetrate the mountains from both the Bering and Arctic sides and render them easily accessible, so that wagons have been taken across them at a number of points without difficulty. Where the mountains abut upon the Bering coast they are broken off by bold sea cliffs, and a magnificent terrace 1 to 4 miles wide with gentle seaward slope has been carved upon their flanks at an elevation of 600 to 800 feet.[a] Westward this feature merges into the York Plateau—a level upland surface ranging in altitude from 200 to 600 feet. The larger streams

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[a] Collier, A. J., A reconnaissance of the northwestern portion of Seward Peninsula, Alaska: Prof. Paper U. S. Geol. Survey No. 2, 1902, p. 37.

have cut wide, shallow valleys in this plateau, and these furnish good wagon roadways of easy grade.

The western extremity of the continent is marked by an isolated mountain mass, known as Cape Mountain, which rises sheer from the water's edge to a height of 2,250 feet. This impressive promontory, usually swathed in chill fogs, forms the American portal of Bering Strait.

There are no harbors in the region and consequently landing is often impossible on account of fog, surf, or storm. The nearest harbor is that of Port Clarence, 20 miles distant.

GENERAL GEOLOGY.

OUTLINE.

The sedimentary rocks of the tin region comprise chiefly limestones and slates, all probably of Paleozoic age. The oldest rocks are a series of impure arenaceous slates of undetermined age. These are overlain conformably by a thick formation of thin-bedded Ordovician limestones (Port Clarence limestone), which generally show no evidence of metamorphism. Near Cape Prince of Wales there is developed a series of crystalline limestones with subordinate siliceous schists and quartzites. These rocks are of "Lower Carboniferous" age, and are faulted off against the slates to the east. Greenstones are common in the slates and a number of granite stocks have invaded the limestones.

The youngest sediments of the region are the gravels, sands, and silts of the Arctic coastal plain. The distribution of the rocks is indicated on the sketch map (fig. 1), in which use has been made of the earlier published results. In the succeeding pages the salient features of the various formations of the York region are briefly described, but no attempt is made to discuss the metamorphic rocks of Ear Mountain under the heading of general geology, inasmuch as their stratigraphic relations are unknown.

SLATES NEAR YORK.

In the vicinity of York a belt of slates 8 or 10 miles wide trends northwestward across the west end of Seward Peninsula. The slates are prevailingly of an impure arenaceous character and exhibit a variable degree of metamorphism throughout the area, though the great bulk of the series consists of but slightly metamorphosed rocks. Typical black clay slates are locally interstratified as thin beds with the more siliceous types. The arenaceous slates are as a rule more or less calcareous or dolomitic. Massive members of the series consist of fine-grained dolomitic sandstone. A graphitic siliceous schist (the graphite, however, is poorly individualized) represents the highest phase of metamorphism in the York region, but this type has no great areal distribution. Petrographically the slates consist chiefly of comminuted quartz and feldspar, and as an accessory mineral a constant though minute amount of clastic brown tourmaline was noted from all parts of the area. In the dolomitic member the quartz grains are generally well rounded, and the carbonate, whose magnesian character was determined chemically, is commonly in the form of small rhombohedra scattered throughout the binding material.

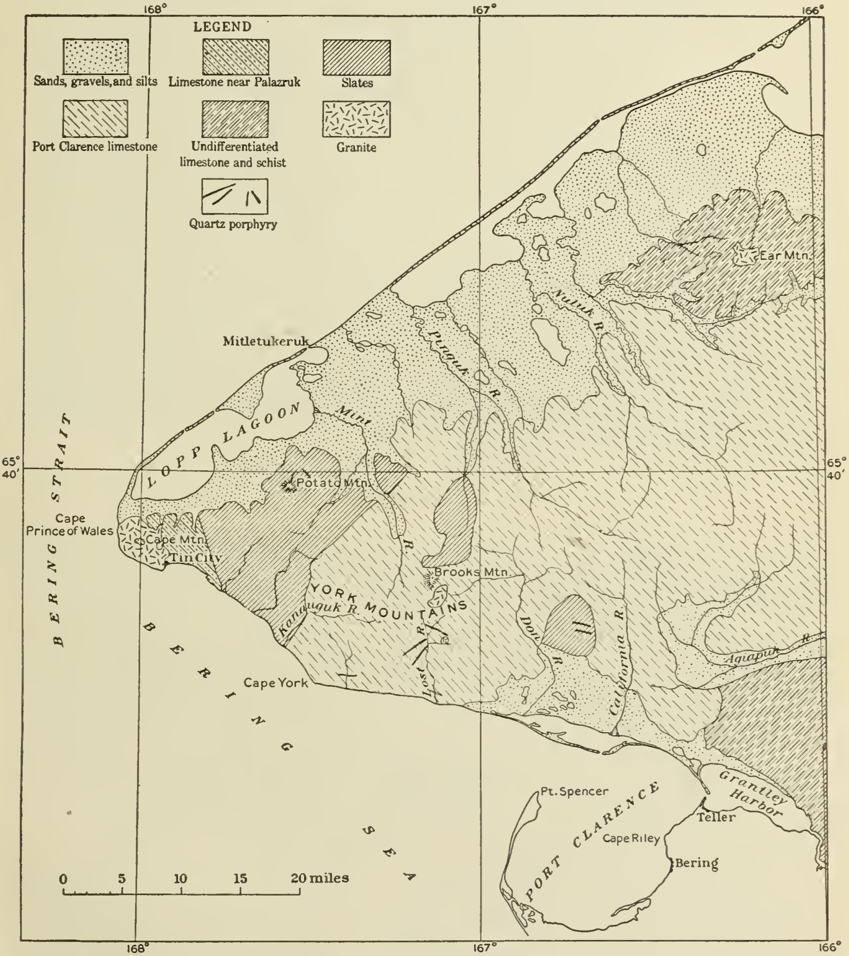

FIG. 1.—Geologic sketch map of the Seward Peninsula tin region.

The degree of cleavage of the slates is variable. The rocks range from nearly massive—rocks little more than shales—to thinly fissile slates. Cleavage and stratification may coincide locally, but within a short distance may stand at right angles. Measurements of strike and dip of the cleavage have little value on account of this abrupt variation, as the sedimentary banding can rarely be observed. These relations are best displayed in the beach section between York and Kanauguk Point. The slates are affected by faults, and one was noted to have offset a dike 400 feet. They are fractured and veined with quartz stringers, some of which carry cassiterite, blue tourmaline, arsenopyrite, and pyrite.

The slates are faulted against a series of crystalline limestones on the west, and underlie the Port Clarence limestone conformably on the east.

PORT CLARENCE LIMESTONE.

The Port Clarence limestone was so named by Collier[a] on account of its typical exposure north of Port Clarence, where it occupies an area of 1,400 square miles. Here it comprises a thick volume of thin-bedded limestones of dense texture, generally unaffected by metamorphism. Four types of rock can be discriminated—an ash-gray variety, a dark lead-gray variety, magnesian and tremolitic phases, and an argillaceous banded variety. The first two are the commonest types, and occur together in interstratified beds. The dark lead-gray limestone forms massive beds up to 6 feet thick, but the ash-gray variety, which is fine grained, like lithographic stone, is thin bedded and commonly breaks into large, thin slabs whose surfaces are covered with fucoid fragments. These limestones were found to be nonmagnesian in the specimens examined, the ash-gray variety containing considerable aluminous material, and the dark lead-gray limestone being pure carbonate rock. Some beds of fine-grained dolomite occur in the Port Clarence formation, but on account of their close resemblance to the prevailing dense-textured limestones their quantitative abundance is not known. Occasionally there occur interbedded with the normal Port Clarence limestones strata which show numerous small prisms of tremolite in random orientation. This is the highest degree of metamorphism displayed by the formation, except for purely local manifestations surrounding granitic intrusives.

The basal portion and lower horizons of the Port Clarence formation consist of an impure banded limestone, the banding being produced by laminæ of argillaceous material. This phase is commonly in a highly contorted condition (Pl. II, *B*). Locally, as at Cassiterite Creek, tremolite has been noted as an abundant constituent, though the possibility is not excluded that the amphibole may have been produced by the action of vein-forming agencies.

In the Lost River region the Port Clarence has a thickness of 2,000 feet. Collier[b] has indicated that the thickness may be as great

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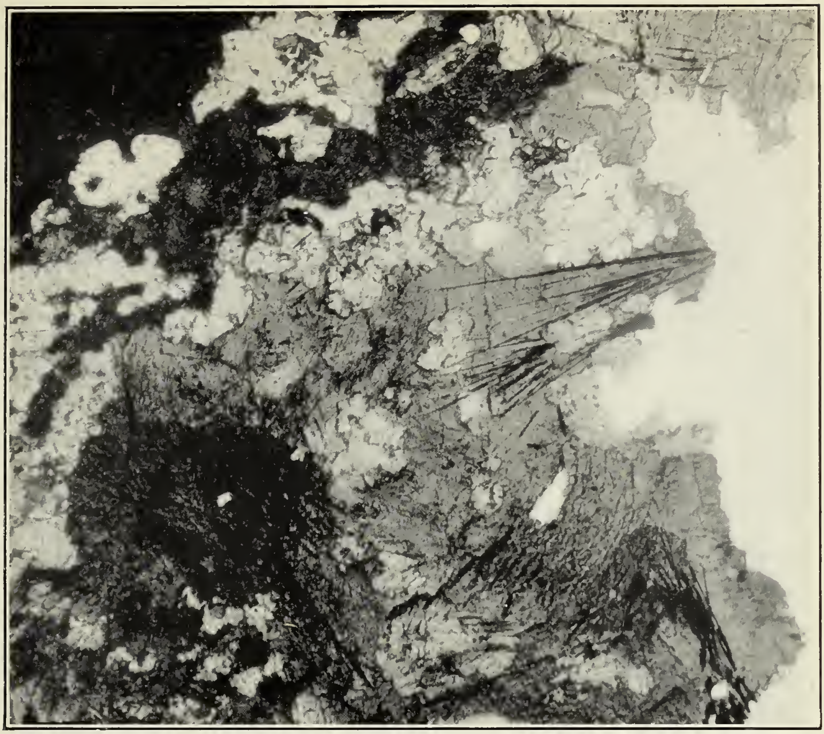
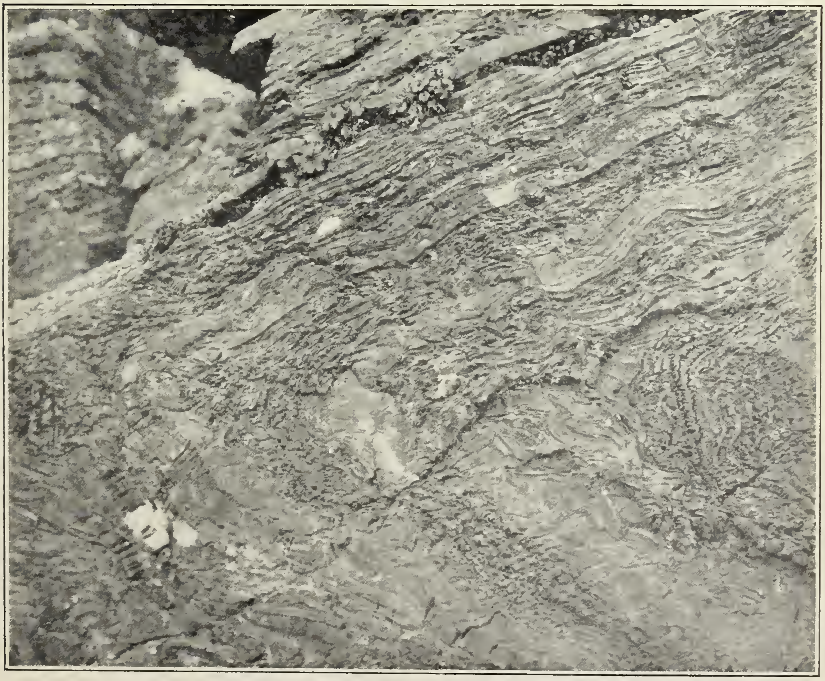
[a] Collier, A. J., Reconnaissance of the northwestern portion of Seward Peninsula, Alaska: Prof. Paper U. S. Geol. Survey No. 2, 1902, p. 18.

[b] Collier, A. J., Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 229, 1904, p. 19.



A. THIN SECTION OF PAIGEITE HORNFELS.

Magnification 60 diameters. Black, opaque fibers of paigeite in tourmaline. Colorless mineral is fluorite.



B. PORT CLARENCE LIMESTONE NEAR HEAD OF CASSITERITE CREEK.

Showing crumpled character of the argillaceous banded variety.

as 5,000 feet, but on account of the prevalence of faults and shatter zones in this region it is probable that the smaller figure is more nearly correct. The dip of the limestone is usually low—about 20° N.—although it may reach as high as 60° along the upper course of Kanauguk River.

The Port Clarence limestone overlies the slates of the York region conformably. As exposed along the western flank of the York Mountains the basal argillaceous schistose limestones of the Port Clarence formation merge imperceptibly into members of the slates, the transitional zone being several hundred feet thick. The same relations are evident on the northwest flank of Brooks Mountain, where the transition is more abrupt, but is marked by an intimate interlamination of slate and limestone. The transition zone has been a zone of weakness, and exhibits more or less severe dynamic deformation. As already indicated, the lower horizons of the Port Clarence are acutely crumpled, locally passing into a brecciated condition. Viewed in the large, however, this phase maintains the appearance of undisturbed and simple structure, characteristic of the Port Clarence as a whole.

Farther east, in the vicinity of Bay Creek, the Port Clarence limestone gives place to the graphitic, chloritic, and calcareous schists characteristic of the Nome region. The exact relations are, however, obscure. In the hills behind Teller Mission the limestone is highly argillaceous and in many places acutely contorted, indicating that the basal portion of the Port Clarence is exposed. According to this interpretation the Port Clarence is regarded as folded into a synclinorium, with one limb exposed on the western flank of the York Mountains and the other at Bay Creek. Subordinate folds have brought the underlying slates into the zone of erosion in isolated areas, as at Brooks Mountain and California River.

The age of the Port Clarence limestone, according to Collier,[a] is either Ordovician or Silurian. The writer found at the head of Cassiterite Creek a few poorly preserved fossils, which, as identified by Kindle, appear to belong to the genera *Raphistoma* and *Liospira*, indicating an Ordovician age.

LIMESTONE NEAR PALAZRUK.

Between the granite headland of Cape Prince of Wales and the mouth of Baituk Creek is a belt of crystalline limestone, which is finely exposed in the cliffs that front Bering Sea. Sericitic siliceous schists, phyllites, and thin-bedded white quartzite are present, but are of very subordinate importance. The siliceous schists find their main

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[a] Collier, A. J., The gold placers of a part of Seward Peninsula: Bull. U. S. Geol. Survey No. 328, p. 79.

development on Cape Mountain, where they are apparently 300 feet thick, and overlie the limestone capping the summit of the granite stock.

A striking feature of the limestone is the variable degree of metamorphism which it exhibits in different parts of the area. It varies from a dense-textured dark-blue limestone on the north side of Cape Mountain to a faintly schistose snow-white marble in the section displayed along Bering Sea.

The thermal metamorphism produced by the granite invasion is strictly local in character. Marmorization extends 200 feet from the intrusive at a maximum, producing a coarsely granular aggregate of calcite crystals several millimeters in diameter. The calcareous quartzites, however, remain unaffected at this distance. In the limestone patch overlying the granite the siliceous laminæ have been converted into wollastonite bands which exhibit a remarkable degree of minute crinkling. Some phases of the limestone show a development of metamorphic minerals unconnected with the presence of visible intrusives. In the old sea cliff 1 mile east of Tin City a series of interstratified ash-gray and dark-blue beds, each individually a few feet or less in thickness, show numerous foils of phlogopite, long prisms and radial groups of tremolite, and cubes of pyrite. Phlogopite is areally the most persistent mineral, and the phlogopite-bearing limestone can be traced as far west as the head of Cape Creek. A certain original content of magnesia is indicated by the formation of phlogopite and tremolite and can be detected chemically in the carbonate of the dark-blue limestone. Whether the formation of these minerals is due to thermal metamorphism is an open question, but the field evidence suggests that it has been caused by the same agency which produced the crystalline marbles—namely, a mild regional metamorphism.

The structure within the limestone area is prevailingly simple. The beds lie nearly horizontal, with a slight easterly dip. Here and there rolls with dips up to 20° occur. Locally individual strata are acutely crumpled and doubled back upon themselves. On the basis of relative degree of metamorphism this limestone would be regarded as the oldest formation in the York region, but paleontologic evidence procured by Collier[a] has shown it to be of Mississippian ("Lower Carboniferous") age—younger than the less highly metamorphosed Port Clarence limestone 8 miles east of it. The limestone appears to be faulted against the slates on the east. Both formations are lying flat near the contact, though locally the limestone may show almost vertical dips. The line of contact, however, does not follow the contours as it should if one horizontal formation were resting

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[a] Collier, A. J., The gold placers of a part of Seward Peninsula: Bull. U. S. Geol. Survey No. 328, p. 81.

upon the other, but cuts across them indifferently. Furthermore, various friction breccias are found in the vicinity of the contact, and an abundant quartz veination occurs in the slates. These features—the shattering, crushing, and local dragging of the strata, and the fact that the contact is independent of the topography—indicate that the limestone is cut off to the east by a fault.

SURFICIAL DEPOSITS.

Surficial deposits have a relatively small distribution in the York region. They comprise the shallow gravels of the present streams and the beach deposits of the narrow coastal shelf bordering Bering Sea. Toward the north, however, all bed rock is mantled by the silts and gravels beneath the low-rolling arctic tundra that stretches between Cape Prince of Wales and Cape Espenberg.[a]

Some of the stream gravels contain local concentrations of gold and placer tin, and are therefore of economic interest.

IGNEOUS ROCKS.

Four stocks of granite are intrusive into the limestones of the region, all quartzose orthoclase granites containing subordinate amounts of sodic oligoclase and biotite, and all prevailingly of a coarsely granular porphyritic habit. They appear to represent contemporaneous intrusions; and as the granite at Cape Prince of Wales is known to invade limestones of "Lower Carboniferous" (Mississippian) age, it is probable that all are post-Mississippian. Together with related quartz-bearing porphyry dikes, they are the most important igneous rocks of the region, inasmuch as the tin deposits are directly associated with them, and their description is therefore given in greater detail under the separate localities at which each occurs.

Greenstones of diabasic character are common in the slate area near York. Where their relations can be determined they are found to be present as intrusive sills. The texture of the greenstones ranges from aphanitic to coarsely granular, and petrographic examination shows that they are composed essentially of chloritized augite and altered plagioclase in ophitic arrangement, with abundant accessory ilmenite and leucoxene. In many places the alteration is exceedingly thorough, but the rocks are unaffected by shearing.

Narrow basalt dikes of rare occurrence are found cutting both limestones and granite, and are therefore the youngest igneous rocks of the region.

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[a] Collier, A. J., Prof. Paper U. S. Geol. Survey No. 2, 1902, p. 25.

MINERALOGY OF THE REGION.

The world's supply of tin is obtained from cassiterite, the dioxide of tin (78.6 per cent Sn). At a very few places stannite, a complex sulphide of copper, tin, iron, and zinc, has been found in sufficient quantities to be raised as an ore, but apparently never for its tin. The stannite formerly found so abundantly in the Carn Brea mines in Cornwall was sold simply for the copper it contained.[a] In recent years only one occurrence is known, namely, at the Oonah mine in Tasmania,[b] where an argentiferous stannite has been mined as a copper-silver ore. The tin was rejected as waste product, but arrangements were finally made with the smelter that for ore containing at least 8 per cent of tin $5 per ton should be paid in addition to the ordinary returns for copper and silver. The latest reports from Tasmania indicate, however, that difficulty has been experienced in treating the stannite ore.[c] At Borah Creek, New South Wales,[d] stannite is also found, and occurs associated with chalcopyrite, arsenopyrite, and galena in a silver-quartz ore. With these two exceptions stannite is of rare occurrence and is not regarded as an ore of tin.

Cassiterite is the only mineral likely to be of economic importance as a source of tin in the Seward Peninsula region. Stannite in association with galena and wolframite is known from one locality only, and there the prospective value of the deposit is probably in silver and tungsten, and not in tin.

Placer gold is found with the stream tin of the York region, but its paragenesis with relation to the cassiterite is unknown.

The Seward Peninsula tin deposits are associated with granitic intrusives which have invaded various series of limestones. The magmas were rich in mineralizers and produced an intense pneumatolytic contact metamorphism along their margins. Conspicuous among the products of this activity are the prevalent boron minerals, tourmaline, axinite, a boron vesuvianite, ludwigite, and two magnesian iron-tin borates new to science, which have been named hulsite and paigeite. Fluorite, scapolite, and chondrodite prove the presence of the halogens in the magmatic exhalations, and sulphur is indicated by the various metallic sulphides that have formed in the contact-metamorphic rocks.

A total of 52 minerals are listed from the region, 16 of which have not previously been recorded and two of which are new species.

Gold.—Some of the streams of the York region carry placer gold. In fact, the prevalence of an undesirable heavy brown mineral in the

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[a] Trans. Royal Geol. Soc. Cornwall, vol. 7, p. 85.

[b] Waller, G. A., Zeehan silver-lead mining field, Govt. Geol. Office, Tasmania, 1904.

[c] Progress of the mineral industry for the quarter ending 30th September, 1907, Govt. Geol. Office, Tasmania, p. 10.

[d] Min. Res. New South Wales, Geol. Survey, New South Wales, p. 120.

sluice boxes of the placer-gold miners led to the discovery of cassiterite and to the search for its bed-rock source. Placer gold is associated with the cassiterite of Buck Creek, the only locality from which there has been an actual production of stream tin, but no authentic figures are available as to the amount of gold obtained per ton of concentrates. Nuggets up to $20 have been obtained.[a]

Stibnite (Sb_2S_3; 71.4 per cent antimony).—Some float stibnite, associated with purple fluorite, was found in the saddle at the head of Tin Creek by H. E. Angstadt, of the Survey party.

Molybdenite.—Molybdenite occurs in sparing amount, associated with cassiterite, in the Lost River region.

Galena.—On Brooks Mountain, galena, associated with an iron-rich zinc blende, occurs intergrown with minerals of contact-metamorphic origin. The Ear Mountain occurrences are of similar nature. In the Lost River region it occurs in fracture zones in the Port Clarence limestone. One occurrence in this region is absolutely unique, namely, galena associated with stannite and wolframite in a vein filling of topaz and fluorite.

Sphalerite.—Sphalerite (zinc blende) of contact-metamorphic origin is common on Brooks Mountain. It possesses a brilliant black luster identical with that of wolframite, with which mineral it has been confused. Analysis by W. T. Schaller shows that specimens contain 19 per cent of ferrous iron. It is distinguished from wolframite by its inferior gravity (sphalerite having a specific gravity of 4 and wolframite of 7.3), greater softness, and more complex cleavage. Wolframite shows but a single cleavage direction; sphalerite may show as many as six. Some thin quartz-tourmaline veinlets carrying pyrite and lustrous black sphalerite were found cutting the granite of Ear Mountain. In this material blowpipe tests were necessary to distinguish the sphalerite from wolframite. A small amount of sphalerite of somewhat resinous appearance is found associated with the tin ore on Cassiterite Creek.

Pyrrhotite.—Magnetic iron pyrites, or pyrrhotite, is found, together with galena and sphalerite of contact-metamorphic origin, on Brooks Mountain. Considerable amounts of it occur in a copper prospect at the mouth of Tin Creek. Small amounts are disseminated in the pyroxene hornfels at Cape Mountain. Pyrrhotite is commonly regarded as stannite throughout the tin region, but can infallibly be distinguished from that mineral by its magnetic character.

Chalcopyrite.—Yellow copper pyrites, associated with pyrrhotite, is found in a fluorite gangue near the mouth of Tin Creek. The lime-silicate hornfels surrounding the granite of Ear Mountain is locally flecked with chalcopyrite.

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[a] Oral communication by F. L. Hess.

Pyrite.—Irregular disseminations of pyrite occur in the granite of Cape Mountain. It is a common constituent in the tin ores of the region, and occurs in the form of rolled nuggets with the stream tin of Buck Creek.

Arsenopyrite.—The silver-white sulphide of iron and arsenic occurs in considerable abundance in the tin ore of Cassiterite Creek, and is found in the contact-metamorphic deposits of Brooks Mountain, associated with tourmaline, fluorite, sphalerite, etc. It occurs with actinolite and cassiterite in the Buck Creek region.

Stannite (tin pyrites; 29.5 per cent copper, 27.5 per cent tin).—The rare mineral stannite, a sulphide of copper, tin, iron, and usually zinc, is known from Lost River only, where it occurs associated with galena and wolframite in a gangue of topaz and fluorite. The Alaskan stannite gives a strong qualitative reaction for zinc. It has a brown-black color and a metallic luster, and possesses an imperfect cleavage. Stannite is a mineral whose identification in any particular case must be confirmed by chemical examination.

Fluorite.—Fluorite occurs in a variety of ways throughout the region—as a contact-metamorphic mineral, as a gangue mineral of tin and of copper deposits, and as a metasomatic replacement of limestone adjoining stanniferous veinlets. It shows a variety of colors—purple, green, yellow, rose—and is also colorless, but the purple is the most common. Specimens from the Cassiterite lode show numerous cubes and, rarely, aggregates of columnar crystals. Fluorite is distinguished from quartz by its relative softness and fine octahedral cleavage. A characteristic feature is its power of phosphorescence, which becomes highly conspicuous during the drying of ore samples.

Quartz.—The granites of the region contain abundant quartz, which is prevailingly of a smoky character. The quartz porphyry dikes contain numerous sharply defined crystals of quartz, and these, too, are commonly smoky, and consequently have been mistaken for cassiterite to some extent. Greasy milk-white quartz (" vein quartz ") carrying cassiterite forms stringers cutting the slates of the York area.

Hematite.—Nuggets of red oxide of iron occur with the stream tin of Buck Creek. Hematite is used as a pigment by the Eskimos of Shishmaref Inlet.

Ilmenite.—Ilmenite occurs as an abundant microscopic constituent of the greenstones, and is largely converted to leucoxene.

Spinel.—Perfect little octahedra of black spinel are found associated with chondrodite in contact-metamorphosed limestone near Read's galena prospect on Brooks Mountain.

Magnetite.—Nuggets of magnetite (magnetic iron ore) are fairly common in the stream tin of Buck Creek. The ore is found in place in visible crystals and clumps associated with calcite, hulsite, and vesuvianite on Brooks Mountain, and occurs also in narrow bands in contact-metamorphic limestone at Tin Creek.

Cassiterite (SnO_2; 78.6 per cent tin).—Cassiterite is a mineral which can not be positively identified by the eye alone. The only convincing test is the actual production, from specimens in question, of beads of metallic tin. On account of the difficulty of recognizing cassiterite the prospectors of the region have mistaken for it a great variety of minerals, including garnet, black tourmaline, augite in quartz porphyry dikes, pyroxene in contact-metamorphosed limestone, smoky quartz, vesuvianite, and wolframite. In color the Alaskan cassiterite varies from black to light yellowish or almost colorless. Some from Cape Mountain and Lost River was noted to show a fair degree of cleavage, which increases its resemblance to pyroxene. The specific gravity of cassiterite is about 7—considerably higher than that of the other minerals mistaken for it, except wolframite. Crushing and panning may therefore serve as a rough test, a gray or colorless residue in the pan indicating cassiterite. But inasmuch as considerable useless prospecting has been done on minerals mistaken for cassiterite, it seems advisable to test the suspected minerals for the only conclusive property of cassiterite—its ability to yield metallic tin. Pebbles and rolled grains of cassiterite occurring in stream gravels are known as stream tin. That of Buck Creek is prevailingly of a brown color, and much of it contains small cavities lined with clear, glassy, yellow crystals. Quartz adheres to many of the larger nuggets.

Rutile.—Rutile occurs as a microscopic constituent in the granites of Cape Mountain.

Pyrolusite.—Perfect dendrites, which are referred to pyrolusite, occur on the joint planes of the limestone near the Cassiterite lode.

Limonite.—Limonite occurs very abundantly in the gossan of galena bodies in the Lost River region.

Calcite.—The limestones in immediate proximity to the granite bosses of the region have been converted into aggregates of coarse white calc spar in many places. On the Dolcoath lode, near Cassiterite Creek, finely crystallized cassiterite occurs embedded in coarsely crystalline calcite associated with danburite, tremolite, and topaz.

Dolomite.—Certain strata of the Port Clarence limestone are composed of dolomite. It occurs also in the form of minute rhombohedra in some of the slates of the York area.

Cerusite.—The gossan of a galena prospect on Tin Creek was noted to contain white crystals of cerusite (lead carbonate).

Azurite.—Rock from the wolframite-topaz lode on Lost River is slightly incrusted with the blue copper carbonate, azurite, doubtless derived from the oxidation of stannite in the ore.

Feldspar.—Large porphyritic crystals of orthoclase and microcline occur in the granites of the region. Albite was detected as a constituent of the wolframite-quartz veins on Cassiterite Creek. Plagioclase is common in the igneous rocks of the region, and in the limestones as a metasomatic mineral.

Pyroxene.—Large crystals of augite, up to 2 inches in size, occur as a constituent of a quartz porphyry dike on Ear Mountain. They are of brown color and rarely show cleavage visible to the eye. They have been mistaken for cassiterite and have occasioned considerable useless prospecting. Augite is approximately half as heavy as cassiterite, and is readily fusible before the blowpipe. By this simple test with the blowpipe, were it available to the prospector, all the minerals usually mistaken for cassiterite, except smoky quartz, might be rejected from consideration. Pyroxene, probably near hedenbergite in composition, is common in the contact-metamorphosed limestone adjoining the granites of the region, particularly that of Cape Mountain. It resembles some of the cassiterite very closely, and the contact rocks have been prospected for tin. This fallacy is encouraged by the fact that the contact rocks are relatively heavy, having a weight corresponding to a 10 per cent quartz-tin ore.

Wollastonite.—Wollastonite occurs on Cape Mountain in proximity to the granite, locally forming white masses up to 3 feet in thickness.

Amphibole.—Tremolite, the colorless variety of amphibole, is prevalent in the form of glistening white fibers in the limestone adjoining the cassiterite occurrences on Cassiterite Creek. It also occurs as fine radial groups in the limestone east of Tin City. The light-green variety, actinolite, constitutes the gangue material of some newly discovered tin-bearing rocks on Buck Creek. Hornblende is common in the limestone adjoining cassiterite veinlets, and gives it a dark-green color.

Garnet.—As a product of contact metamorphism garnet is of widespread occurrence, the finest specimens coming from Tin Creek, on Lost River. It is commonly crystallized in rhombic dodecahedral forms, yielding diamond-shaped faces. Where only the apex of the dodecahedron is visible garnet bears a deceptive resemblance to the four-sided pyramid characteristic of cassiterite. Vesuvianite is usually associated with the garnet.

Olivine.—Olivine forms part of the basalt dikes of Cape Mountain, and is noted only microscopically.

Scapolite.—Chlorine-bearing scapolites are found in specimens of lime-silicate hornfels from Ear Mountain and Cape Mountain. Its identification is possible only by microscopical and chemical methods. In a number of specimens it was found that the birefringence, as indicated by the negative uniaxial interference figures, ranged from low to comparatively high values in the same thin section.

Vesuvianite.—Vesuvianite is one of the commonest contact-metamorphic minerals of the region. It is especially prevalent on Brooks Mountain and along the headwaters portion of Yankee Creek, where fine crystals showing ideal development occur in great abundance embedded in a matrix of coarsely crystalline calcite. The color of the vesuvianite is some tone of green, ranging from gray-green to brown-green. The crystals are usually in the form of square prisms.[a] As radial aggregates and branching forms, vesuvianite associated with garnet is abundant near the granite of Tin Creek on Lost River. It also forms metasomatically near stanniferous veinlets in limestones.

Zircon.—Zircon is noted as a microscopic constituent of the granites of the region.

Danburite.—The rare borosilicate of lime, danburite, was identified as the gangue material of cassiterite in the Dolcoath lode on Cassiterite Creek, where it occurs as replacement both of the dike rock and of the contiguous limestones. (For partial analysis see p. 52.) The optical properties of the danburite in thin section are indecisive; it is colorless and biaxial and shows the interference tints of feldspar and a relief near that of the associated tourmaline.

Topaz.—As a constituent of the tin ore in the Lost River region topaz (fluosilicate of aluminum) is exceedingly abundant. It occurs in altered quartz porphyry dikes, as vein mineral in veinlets in limestones, and as a metasomatic product in the limestone adjoining such veinlets. It is commonly associated with fluorite and zinnwaldite. The most remarkable occurrence, however, is that on the Oregon claim, where delicately radial topaz with subordinate fluorite forms the gangue of an argentiferous ore containing wolframite, galena, and stannite. (For analysis see p. 58.)

Zoisite.—Zoisite occurs in small amount in lime-silicate hornfels on Ear Mountain.

Epidote.—Radial groups of epidote are found on Brooks Mountain near the granite contact.

Axinite.—Small crystalline aggregates of axinite occur in a tourmaline hornfels from Ear Mountain. It is highly glassy in appearance and of a peculiar brown color. Many of the crystal faces are striated and acute edged. Axinite also occurs microscopically in a contact-metamorphic deposit on Brooks Mountain, associated with tourmaline, fluorite, arsenopyrite, and sphalerite.

Chondrodite.—Small honey-yellow crystals of chondrodite occur, together with numerous minute black octahedra of spinel, in a contact-metamorphosed limestone on Brooks Mountain.

Tourmaline.—Tourmaline is exceedingly common throughout the entire region and is regarded by many of the local prospectors as an

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[a] Forms measured crystallographically are given in Am. Jour. Sci., 4th ser., vol. 25, 1908, p. 323.

infallible indication of tin ore. Although it is true that tourmaline is pretty generally associated with cassiterite, it is far from true that cassiterite is always associated with tourmaline. Great deposits of tourmaline that carry no tin whatever are known in various parts of the world.

In the Seward Peninsula tin region tourmaline occurs in a great variety of ways. It is found in granite apophyses on Ear Mountain as an original constituent (of the pneumatolytic stage of consolidation). It forms an essential mineral of the lime-silicate rocks surrounding the granite and occurs along seams and stringers in the granite itself, and in the quartz porphyry dikes with fluorite, arsenopyrite, and possibly cassiterite. On Cape Mountain it is abundant in the granite, and also occurs embedded in coarsely granular calcite. In the Buck Creek area the quartz stringers contain small rosettes of blue tourmaline. It is common in the Lost River and Brooks Mountain regions. Black, dark blue, and more rarely brown green are the prevailing colors. It is commonly crystallized in three- and six-sided prisms and columns, generally arranged in radial groups. As a rule the columns are aggregated together, and it is therefore usually difficult or impossible to distinguish the geometric form of individual crystals. Tourmaline has a specific gravity of 3, or less than half that of cassiterite. This property and its form, where discernible, are its most characteristic differences from cassiterite, with which it has frequently been confounded.

Muscovite.—White mica occurs at Ear Mountain in granite tongues extending from the central mass out into the surrounding sedimentary rocks.

Zinnwaldite.—The lithium-iron mica, zinnwaldite, occurs abundantly in the cassiterite veinlets on Cassiterite Creek, and is habitually associated with topaz and fluorite. It resembles muscovite, both to the eye and under the microscope, but differs from it by possessing a smaller axial angle. It fuses readily to a black magnetic globule. (For analysis see p. 54.)

Biotite.—The granites of the region contain black mica as a subordinate constituent in the form of small lustrous plates. It occurs also in a pegmatite on Brooks Mountain, in plates up to one-half inch in size.

Phlogopite.—Phlogopite, the magnesia mica, is found as small flakes associated with vesuvianite in contact-metamorphosed limestone on Brooks Mountain, and with tremolite is abundant in the limestone east of Tin City.

Chlorite.—Chlorite is common in the greenstone of the slate area near York.

Kaolin.—Kaolin occurs abundantly as an alteration product in the Cassiterite lode.

Apatite.—Apatite occurs as a microscopic constituent of the granites.

Ludwigite ($3MgO.B_2O_3+FeO.Fe_2O_3$).—A finely fibrous dark-green mineral, soluble in hydrochloric acid, forms small radial aggregates in a contact-metamorphosed limestone from Brooks Mountain. It gives a decided flame reaction for boron, and is therefore tentatively identified as ludwigite.

Paigeite.—The new boron-tin mineral, paigeite,[a] was found at two localities, near Read's cabin on Brooks Mountain in loose blocks and at Ear Mountain in situ. The Brooks Mountain material is intergrown with vesuvianite, calcite, and hedenbergite, with subordinate biotite and arsenopyrite in sporadic grains. At Ear Mountain it occurs evenly disseminated through a tourmaline-lime-silicate hornfels consisting essentially of calcite, tourmaline, vesuvianite, fluorite, and zoisite, with accessory phlogopite, chalcopyrite, and magnetite. It is a lustrous coal-black foliated mineral, and has a hardness of about 3, with a density of 4.71. Analysis of material from Brooks Mountain gave the following result, which is recalculated on the basis of 100 per cent; it contains probably 15 per cent SnO_2:

Analysis of paigeite from Brooks Mountain.

FeO	51.99
MgO	1.68
Fe_2O_3	19.54
H_2O	2.37
SnO_2 B_2O_3	24.42
	100.00

Hulsite.[b]—On the northwestern flank of Brooks Mountain a prospect cut has been opened on a showing of contact-metamorphic minerals occurring in a marmorized limestone 10 feet from the granite contact. Examination of this deposit indicated that an unknown mineral, which subsequent investigation proved to be a new boron-tin mineral, was present in considerable abundance. Hulsite, as the mineral was named, is closely associated with magnetite and a boron vesuvianite in a matrix of coarse calc spar, in which garnet and fluorite occur in subordinate amounts. The characteristic features of the new mineral are its strong submetallic luster, black color, good cleavage after the prism of 57° 38′, and tendency toward a tabular development. Its hardness is about 3; density, 4.28. It contains probably 20 per cent SnO_2.[c]

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[a] Knopf, A., and Schaller, W. T., Two new boron minerals of contact-metamorphic origin: Am. Jour. Sci., 4th ser., vol. 25, 1908, p. 323.

[b] Op. cit., p. 323.

[c] Chemical work is at present in progress by W. T. Schaller, with a view to determining the formulæ of hulsite and paigeite. It appears that the original determinations of B_2O_3 were defective, so that the formulæ proposed are untenable.

Wolframite ($Fe,MnWO_4$; 76.4 per cent tungsten trioxide).—The valuable mineral wolframite occurs associated with cassiterite on Cassiterite Creek and with galena and stannite in a topaz-fluorite gangue on the Oregon claim on Lost River. Its distinguishing features are its great weight (specific gravity, 7.3), black color, and brilliant submetallic luster on fine cleavage surfaces. Its hardness is 5.5, which means that it can be rather readily scratched with a knife. The resemblance of wolframite to the iron-rich zinc blend of Brooks Mountain has already been pointed out.

Scheelite ($CaWO_4$; 80.6 per cent tungsten trioxide).—The mineral scheelite has been detected as a microscopic constituent of certain lime—silicate contact rocks of Cape Mountain. It was also found as minute grains in a number of small cassiterite veinlets on Cassiterite Creek and in the altered limestone adjoining the veinlets. As an alteration product it forms microscopic coatings around wolframite crystals. None of these occurrences are of possible commercial importance. Scheelite is a heavy white mineral of vitreous luster, having a specific gravity of 6 and a hardness ranging from 4.5 to 5.

ECONOMIC GEOLOGY.

OUTLINE.

Tin ore occurs in both lode and placer form, but up to the present time practically the only production has been from the placers of a single stream—Buck Creek. Placer tin is known to be widely distributed in the streams of Seward Peninsula,[a] and has been found in some of the gold placers near Nome, but in amounts that are commercially unprofitable.

Cassiterite is the only mineral that is likely to prove of economic value as a source of tin. Stannite is also known to occur, but at one locality only, where it is associated with galena in a remarkable argentiferous wolframite-topaz ore. Two new tin minerals (magnesian iron-tin borates) have been discovered, but on account of their low tin content (approximately 15 per cent SnO_2) are probably not worth exploitation.

The lode-tin deposits are genetically associated with the granitic intrusives, and on account of the abundance of limestone in the region the Seward Peninsula tin occurrences possess a number of unique and distinctive features. A variety of pneumatolytic contact rocks have been produced around the margins of the granites, and certain of these contain the iron-tin borates (hulsite and paigeite) as essential constituents. The resemblance of numerous heavy contact-meta-

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[a] Collier, A. J., Recent developments of Alaskan tin deposits: Bull. U. S. Geol. Survey No. 259, 1905, p. 127.

morphic minerals, such as garnet, to cassiterite, coupled with the fact that some of the contact-metamorphic rocks are actually stanniferous, has led to much prospecting along the granite-limestone contacts. Only one contact rock containing cassiterite in amounts appreciable under the microscope was found, however, during the course of the present investigation.

Tin-bearing rock occurs also in tourmalinized granite, in fractured quartz porphyry dikes cutting limestone, and in the adjoining limestone itself, intergrown with danburite, tourmaline, tremolite, and topaz. Cassiterite is found in quartz stringers in granite, in slate, and in limestone, accompanied by an intense metasomatism. Veinlets in limestone may consist wholly of cassiterite, topaz, zinnwaldite, and fluorite. In the slate area cassiterite also occurs embedded in tabular masses of radial actinolite which appear to be interstratified with horizontal slates.

Most of the prospects have been but imperfectly opened. Some are of promising character, but from the point of view of the conservative mining man their value is yet to be demonstrated.

Each of the four localities at which lode tin is being prospected—Ear Mountain, Buck Creek, Cape Mountain, and Lost River—shows certain distinctive features, so it has been found advisable to describe them separately in geographic order, as enumerated. To these has been added Brooks Mountain, on which some stanniferous contact-metamorphosed limestone has been found, though no cassiterite-bearing rock has yet been discovered there.

LODES.

EAR MOUNTAIN.

INTRODUCTION.

Ear Mountain is located in the northwestern part of Seward Peninsula, in latitude 66° north and longitude 166° west. It is 50 miles north of Teller and 15 miles south of Shishmaref Inlet, a large, shallow embayment from the Arctic Ocean. The region is not readily accessible, and with the present means of communication it is practically impossible to bring in supplies during the summer months. Steamers of light draft do not venture to approach nearer than within 1½ miles of Sarichef Island, at the mouth of Shishmaref Inlet, though gasoline schooners make landings directly on the island. The inlet itself is not navigable other than by oomiaks and flat-bottomed dories. The first steamer of the season of 1907 bound for arctic points passed northward through Bering Strait on July 2. At this time the last ice floes from the spring break-up were drifting out of Shishmaref Inlet.

Ear Mountain has long, smooth slopes on the north and east sides, but on the south and west sides rises abruptly above the tundra-covered plateau from an elevation of 1,000 feet to a maximum of 2,308 feet above sea level. The mountain possesses two flat-topped summits, of which the southern is slightly the higher. Two great granite monoliths rest upon the broad northern summit, and are visible, but as very diminished objects, from ships on the Arctic Ocean, 20 miles distant. They were noted by the early navigators, and from them the mountain received its rather fanciful name.

Cassiterite in the form of stream tin was accidently discovered on Eldorado Creek, on the northeast side of the mountain, in 1901. Nuggets several inches in diameter can be picked off the bed-rock riffles of this stream, but on account of the small body of gravel the creek offers no placer possibilities. The bed-rock source of this cassiterite has not yet been discovered. None of the rocks that are being prospected show visible cassiterite, and only a few show small amounts microscopically. Attention has lately been directed to some occurrences of chalcopyrite and galena found in contact-metamorphic rock.

GENERAL GEOLOGY.

The rocks flanking Ear Mountain are prevailingly of a calcareous character, and comprise contorted limestone and lime-mica schists. On the south side of the mountain some black siliceous schists appear. Intrusive into these sedimentary rocks and forming the core of Ear Mountain is a large mass of coarsely crystalline granite from which numerous apophyses of fine-grained white granite extend into the surrounding sedimentary rocks. (See figs. 2 and 3.) The limestones were highly susceptible to contact metamorphism and succeeded to an unusual extent in fixing the magmatic emanations in such minerals as tourmaline, axinite, paigeite (a magnesian iron-tin borate), fluorite, scapolite, galena, and chalcopyrite.

The youngest rocks of the region occur as quartz-augite porphyry dikes cutting both limestone and granite. The two most prominent of these dikes are 15 feet thick and can be traced for several thousand feet, striking N. 30° E. and north and south (magnetically).

Granite.—The granite of Ear Mountain consists of feldspar (orthoclase with subordinate amounts of oligoclase-albite and microperthite), quartz, and biotite. Both quartz and feldspar tend to assume idiomorphic forms, even in the coarsest grained phases. The quartz is smoky, and has not infrequently been mistaken by the prospector for cassiterite, especially where the color was more intense. Near the contacts the granite is finer grained, and is, in many places, a typical granite porphyry. In the central portion of the main granite body a small area of this type of rock was found, but whether it represents a mere variation in texture or a separate intrusion could not be determined. Black tourmaline is common in the granite of Ear Mountain, but is always associated with seams consisting of quartz and

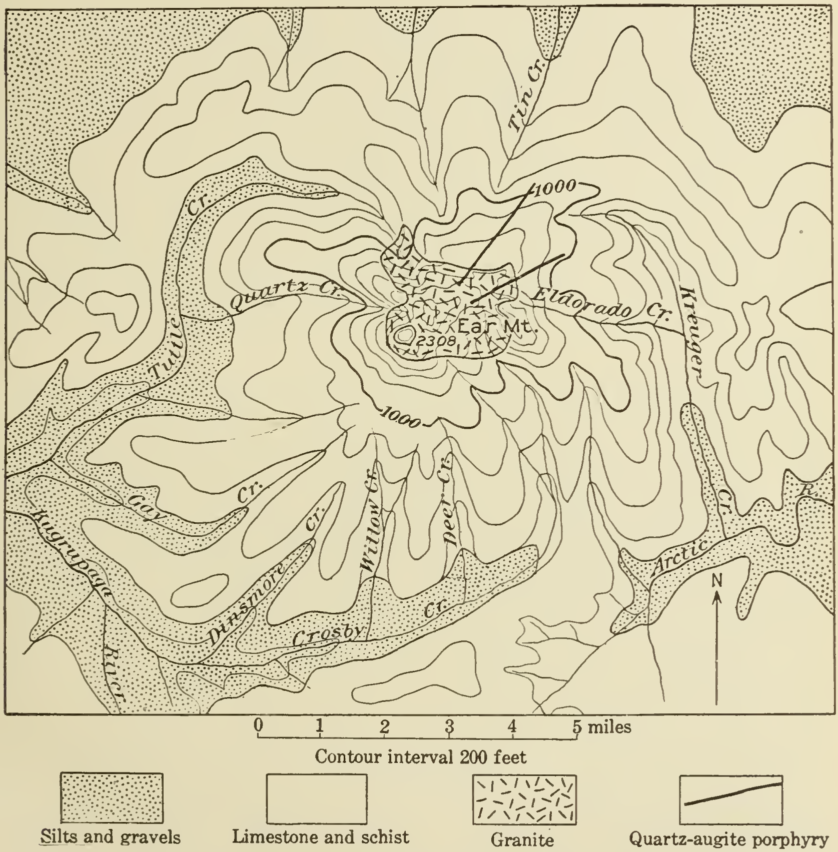

FIG. 2.—Geologic sketch map of Ear Mountain.

tourmaline, and adjoined by bands of tourmalinized granite 2 or 3 inches broad. The quartz-tourmaline seams, on account of their resistance to atmospheric attack, weather out in relief. Several such

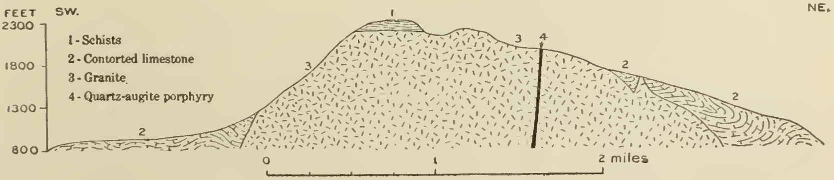

FIG. 3.—Geologic section through Ear Mountain.

seams can be seen running up and down the "Ears"—the granite monoliths from which the mountain was named.

The offshoots from the main granite body are finer grained and lighter colored. They contain, besides quartz and feldspar, white mica, and in many places numerous small prisms of tourmaline, evenly distributed throughout the body of the rock and unconnected with the presence of seams. In addition to the constituents visible to the unaided eye, the microscope shows a small amount of topaz. Some fluorite is associated with the muscovite, which, like the topaz, occurs in skeletal growths. Minute cassiterite prisms surrounded by pleochroic halos occur embedded in the muscovite. The tourmaline, which is brown, usually occurs in discrete prisms, but may also form skeletal growths. The three minerals—muscovite, topaz, and tourmaline—were formed after the feldspar and quartz, and apparently by similar processes. They are absent from the granite of the main mass, and indicate an enrichment of fluorine and boron in the apophyses.

Contact metamorphism.—An extensive development of lime-silicate hornfels, rich in the so-called pneumatolytic minerals, has been produced around the periphery of the granite mass. The limestones that were metamorphosed were originally impure limestones irregularly laminated with thin bands (one-eighth to one-fourth inch thick) of argillaceous material. The contact metamorphism has consisted in part in a recrystallization of the sedimentary material and in part in an accession of new material by magmatic emanations.

The simplest case of contact metamorphism is that of the tourmalinized limestone formed on the south side of Eldorado Creek. Here the argillaceous laminæ have been converted into black tourmaline and the calcareous bands have been marmorized, producing a rock resembling a gneiss. The tourmaline is pleochroic in tones of blue and green. Tremolite has also been developed, with diopside and vesuvianite in minor amounts. At other points along the contact the original banded character of the limestone is preserved, and even emphasized, by the production of trains of vesuvianite crystals. On Quartz Creek the limestones have been converted into pyroxene-scapolite hornfels. A prospect cut at this locality exposes a dark-colored rock, evenly flecked with a lustrous coal-black lamellar mineral, which subsequent investigation has shown to be a new boron-tin mineral, and which has been named paigeite.[a]

In addition to the paigeite, considerable tourmaline and minor amounts of chalcopyrite and magnetite are visible. Under the microscope the rock resolves itself into a confused intergrowth of zonally banded tourmaline, calcite, vesuvianite, zoisite, paigeite, fluorite, and accessory phlogopite, chalcopyrite, and magnetite. The paigeite is embedded in the various other constituents in trichite-like forms,

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[a] Am. Jour. Sci., 4th ser., vol. 25, 1908, p. 323.

many of which are of capillary dimensions, and in matted aggregates of fibers (Pl. II, *A*). Closely associated with this paigeite hornfels is a tourmaline-pyroxene-scapolite hornfels, which reacts chemically for chlorine. A prospect opening at the granite-limestone contact near Tuttle Creek reveals a tourmaline-axinite hornfels. The axinite is of highly vitreous appearance and of light-brown color, and is therefore readily recognizable in the hand specimen. It reacts for boron and manganese. In thin section it is colorless with faint blue pleochroisms, but shows no recognizable cleavage, although agreeing otherwise in its optical properties with those cited by Rosenbusch. Tourmaline is quantitatively more important than the axinite in this hornfels. It is subhedral and in numerous places zonally banded. with pleochroism varying from blue to green. In addition to the tourmaline and axinite, actinolite, pyroxene, quartz, fluorite, and calcite are confusedly intergrown, though the last three minerals occur rather in minor amounts. Some cassiterite is found embedded in the other constituents in grains large enough to allow its optical identification beyond question. This tourmaline-axinite hornfels is the only contact-metamorphic rock containing cassiterite found in the entire Alaskan tin region, although a large number of such rocks were examined on account of the prevalent belief that they are tin bearing.

Quartz-augite porphyry dikes.—The quartz-augite porphyry dikes consist of a dense-textured rock of dark-blue or green color containing numerous phenocrysts of feldspar and smoky quartz, with lesser amounts of augite and biotite. The augites attain unusually large dimensions—as much as 2 inches or more—and are commonly regarded as " tin crystals " by the local prospectors. The presence of these augite phenocrysts thus mistaken for cassiterite has led to considerable prospecting of the quartz porphyry dikes. In thin section the quartz phenocrysts are seen to be corroded and embayed; the plagioclase, which corresponds to bytownite ($Ab_{25}An_{75}$), is also corroded. Augite and biotite are rare. The groundmass consists of plagioclase laths approximating $Ab_{40}An_{60}$ in composition, and they are disposed in fluxional arrangement. Apatite is unusually abundant. According to this characterization the dikes are augite dacites. Calcite and tourmaline are common as secondary minerals. Where tourmalinization has been more intense fluorite, arsenopyrite, and cassiterite appear.

Two periods of tourmalinization can therefore be distinguished—one contemporaneous with the contact metamorphism and one following the intrusion of the augite dacite dikes. That a considerable lapse of time separated these periods is indicated by the fact that the granite now exposed to view had become thoroughly cooled during this interval and was able to chill the later intrusives.

MINERAL OCCURRENCES.

In addition to vesuvianite, tourmaline, axinite, and other contact-metamorphic minerals, the contact rocks at certain localities are flecked with galena, chalcopyrite, and a lustrous coal-black iron-tin borate, which has been named paigeite. It is this type of rock which has raised hopes that copper and lead deposits of economic value exist at Ear Mountain. Cassiterite-bearing rock also is believed by the prospector to occur along the contact at many points.

The practical importance of understanding how the deposits were formed arises from the following considerations:

(1) That the size and persistence of the deposits are dependent on the mode of origin.

(2) That their probable value, besides being affected by the size and persistence of the deposit, is also dependent on the mode of origin.

Under the first heading attention may be drawn to certain structural features of the granite boss of Ear Mountain—features which also occur at Cape Mountain and at Brooks Mountain. It can be shown from various lines of evidence that any such granite mass as that of Ear Mountain must have cooled under a considerable blanket of protecting rocks. The surface of the granite against these overlying rocks is not necessarily smooth, but may be of gently undulating character, or may even be furrowed by sharp ridges, such as, for instance, have been revealed by the extensive mining operations in Cornwall. The troughs or depressions between these granite ridges will be occupied by the overlying rocks, which will therefore appear immersed beneath the general surface of the granite. At Ear Mountain erosion has proceeded far enough to strip off much of the protective capping of sedimentary rocks which formerly arched over the granite, though on the highest peak—the south peak—the granite is still covered by a thickness of 100 feet of schists and sheared greenstone. This erosion has revealed the fact that the former surface of the granite boss was slightly uneven. The limestones and schists resting in the inequalities now occur as isolated patches surrounded on all sides by granite. A section across Ear Mountain (fig. 4) illustrates this feature. These rocks may

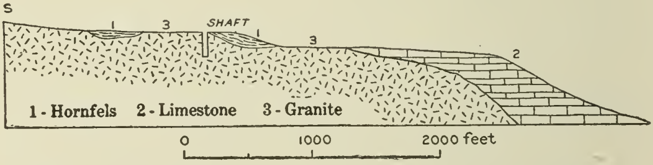

Fig. 4.—Diagrammatic section at Eunson's shaft, Ear Mountain.

show locally indications of ore, but the rock, being of contact-metamorphic origin, will have a small areal extent, will have no great depth, and will give out when the underlying surface of the granite is reached. The prospector, therefore, should use considerable caution before attempting any exploitation of ore bodies occurring in such patches of rock lying upon the surface of the granite.

Along the periphery of the granite the ore deposits of contact-metamorphic origin are more likely to have permanence in depth. What is known of contact-metamorphic deposits in other parts of the world, however, is not of a character to encourage extravagant hopes for the similar occurrences found at Ear Mountain. They are usually of low grade and irregular in form. Such deposits are mined in southeastern Alaska for their copper content, but conditions must be exceptionally favorable to make them of commercial value.

On the northeastern side of the mountain, near Vatney's cabin, where the contact metamorphism has been more pronounced than usual, some metamorphosed limestone in proximity to a granite dike was being prospected for tin ore. It contains small bunches of a reddish-brown mineral showing crystal faces, which, when carefully examined, are seen to be diamond shaped. This is typical of garnet. When only the apex of the garnet crystal is visible it bears an exceedingly deceptive resemblance to the four-sided pyramid characteristic of cassiterite.

Near Tuttle Creek a prospect trench has been opened to uncover some contact-metamorphosed limestone at the granite contact. The stanniferous tourmaline-axinite hornfels whose microscopic features have already been described occurs at this locality, but no cassiterite is visible in the rock to the unaided eye. The microscope, however, shows the presence of a small fraction of 1 per cent—an amount too small, in view of the nature of the deposit and the remoteness of the region, to give rise to any extensive hopes that commercial bodies of cassiterite exist along the contact.

The quartz-tourmaline seams that cut the granite have already been described. At various places on Ear Mountain interlacing networks of such seams occur, and an extensive tourmalinization of the adjoining granite has taken place. Masses of quartz-tourmaline rock have been produced, little resembling the original granite. Such occurrences have been opened by shallow prospect pits at a number of points. It is quite possible that some deposits of this character may carry low-grade values in tin, but those opened thus far lend small encouragement to this idea.

On the northeast side of Ear Mountain an augite-quartz porphyry dike has been opened by a shaft and explored by a drift 112 feet long.

Nothing but hard, barren rock was encountered. Work was suspended, and at the time of visit the shaft was flooded with water. Farther southwest on the extension of the same dike a number of open cuts have been made on account of the prevalence of numerous large augite crystals embedded in the dike rock. Chemical analyses of "ore" samples, made in the laboratory of the Survey, show the presence of only traces of tin, amounting to a few hundredths of 1 per cent.

A shaft known as Eunson's shaft (fig. 4) was sunk near the point where a quartz porphyry dike striking north and south crosses the granite-limestone contact. The shaft was reported to be 30 feet deep, but at the time of visit was flooded with water and partly caved in. On the dump a variety of rock is represented. Contact-metamorphosed limestone, granite, granite porphyry, quartz porphyry, and various altered modifications of the quartz porphyry appear. The quartz porphyry is partly tourmalinized and contains small patches of purple fluorite, abundant arsenopyrite, and microscopic grains of cassiterite. The tin ore reported from this locality probably came from highly altered portions of the quartz porphyry dike.

BUCK CREEK.

GEOLOGIC FEATURES.

The Buck Creek area is a part of the slate belt previously described. The bed rock consists of fine-textured arenaceous slates, usually lying flat. Along Buck Creek the rocks do not display a highly metamorphosed aspect, but are in large part shalelike, associated with beds of banded yellowish fine-grained sandstone and bluish kaolinic sandstone. The slaty cleavage, however, is developed in an irregular and variable degree in different parts of the area. At the head of Sutter Creek the arenaceous banded rock is thinly fissile, with the cleavage at right angles to the sedimentary banding. Greenstones of diabasic character occur with the slates, but can rarely be found in place. A prominent exposure, however, forms a low ridge immediately to the north of Buck Creek.

Two quartz porphyry dikes cut the slates at the head of Buck Creek. The characteristic feature of these dikes, especially of the one extending northward from Potato Mountain, is the abundance of large quartz phenocrysts, many of them smoky, embedded in a dense light-gray matrix. The feldspars are less conspicuous. The margins of the dikes have been strongly chilled, and show a bluish-black rock containing small phenocrysts of quartz and feldspar. On the summit of Potato Mountain the dike is but 1 foot thick and consists entirely of this kind of rock. Farther north the thickness increases to 10 feet. The other quartz porphyry dike, which trends N. 34° W. (magnetic), has a maximum thickness of 50 feet and a length of several thousand feet. These are the only acidic igneous intrusives known in the region.

ECONOMIC GEOLOGY.

Cassiterite occurs in three ways in the bed rock of the Buck Creek area—(1) as an impregnation in quartz porphyry dikes, (2) in quartz stringers cutting the slates, and (3) intergrown with arsenopyrite in a gangue of radial actinolite. Development, however, has not yet proceeded far enough to demonstrate the commercial importance of any of these occurrences.

At numerous points on the ridge of hills at the head of Buck Creek open cuts have made made, exposing networks of quartz stringers in the slates. The veinlets are usually a few inches thick, and here and there contain cassiterite. Some merely show rosettes of blue tourmaline or are barren. Gold is probably present in some of them, as placer gold is found in the stream tin of Buck Creek. On the divide, at an altitude of 1,140 feet, a prospect pit discloses a fine showing of tin quartz. The hole is 10 feet deep and exposes a face of 7 feet of quartz carrying a considerable percentage of cassiterite. The developments are inadequate to give either dip or strike of the ore body with any degree of certainty, nor is its linear persistence known. The depth attained is not great enough to expose solid bed rock, and the walls are consequently still in a highly shattered condition due to the heave of the frost. The ore is a milk-white quartz of greasy luster, and contains cassiterite disseminated through it in crystalline aggregates, intimately intergrown with arsenopyrite and small needles of blue tourmaline. In thin section the tourmaline is found to be light blue in color, the pleochroism varying from clear blue to colorless (alkali tourmaline). The slate wall rock has a greenish cast, and under the microscope is found to consist almost entirely of minute tourmaline prisms in parallel orientation, with a small amount of interstitial feldspar. The bright boron flame which the slate yields when treated with fluorite mixture abundantly confirms the microscopic diagnosis. About 60 feet from the prospect pit the outcrops consist of normal arenaceous slate lying nearly horizontal.

At the head of Peluk Creek (a small tributary of Buck Creek) a shaft, reported to be 20 feet deep, was sunk on quartz stringers in the slate. The material on the dump shows abundant pyrite and a little cassiterite. In the same general vicinity float tin ore has been discovered in which the cassiterite occurs in totally different paragenetic association. It is found embedded in a green rock composed of radiating groups of actinolite. Relatively large amounts of arsenopyrite are usually intergrown with the cassiterite. A number of open cuts have been made in the effort to locate the bed-rock source of this tin-bearing rock. At time of visit the owner of the property had just succeeded in uncovering the edge of the deposit in place, so that few facts are available as to its geologic relations and probable value. Where exposed it was highly oxidized, and apparently represented a tabular mass intercalated between horizontal slates. In thin section the ore rock consists of sheaf-like bundles of actinolite, with which some finely granular calcite is associated. A small amount of quartz occurs in the immediate vicinity of the cassiterite, and both these minerals are transfixed by needles of actinolite (Pl. III, *A*). Tourmaline in the form of a few small prisms occurs as an accessory mineral. The slate in contact with the stanniferous rock is of a dense, poorly fissile variety. Under the microscope it shows no decided evidence of metasomatic alteration. It contains abundant magnetite disseminated through it in minute grains, which may possibly be of epigenetic origin.

At a number of points the quartz porphyry dikes are somewhat impregnated with pyrite, especially in the vicinity of seams. A small amount of tourmaline in radial groups appears, and white mica replaces the feldspar phenocrysts. Specimens containing a small amount of cassiterite have been obtained, but appear to be of extremely rare occurrence. The largest quartz porphyry dike has been faulted approximately 400 feet in a north and south direction. The line of this fault is marked by a great quartz vein 15 feet or more in thickness, which can be traced for considerably over a mile. The vein contains a vast number of slate fragments, each of which has acted as a nucleus around which quartz crystals commenced to grow. Failure of the crystals to coalesce in their outer extremities has produced a vuggy vein lined with innumerable hexagonal pyramids of quartz. No mineral except some botryoidal limonite incrusting the quartz crystals has been observed in the vein, so that it is without economic importance. Whether the formation of this vein was contemporaneous with that of the stanniferous quartz veinlets is of considerable practical interest. If of the same period of origin there is a strong possibility that persistent tin-quartz veins may yet be found in the slate area.

ORIGIN OF THE ORES.

The developments and exposures are entirely too inadequate to allow a very extended discussion of the origin of the ores. From analogy with the Lost River area, however, it is believed that a granite mass underlies the Buck Creek region and that the quartz porphyry dikes represent the final expulsive effort of this magma. After the advent of the porphyry emanations carrying metallic salts in solution

A. THIN SECTION OF ACTINOLITE-CASSITERITE ROCK; CROSSED NICOLS.

Magnification 32 diameters. Shows cassiterite transfixed by actinolite needles.

B. THIN SECTION OF STANNIFEROUS METAMORPHOSED LIMESTONE FROM BROOKS MOUNTAIN.

Magnification 12 diameters. Hulsite (black opaque mineral) intergrown with vesuvianite in a matrix of calcite.

ascended from unknown depths. These solutions moved in part along preexisting lines of weakness marked by the quartz porphyry dikes and in part along fractures in the slates. They contained the elements silicon, oxygen, sulphur, arsenic, boron, iron, aluminum, and tin, and probably gold. The metasomatic alterations indicate that the solutions were at high temperatures. The actinolite rock was probably produced by stanniferous solutions which, as leakages from the main channels of circulation, moved laterally through impure dolomite beds, such as the petrographic study of the slates has shown to occur through the region. The association of cassiterite and arsenopyrite in a gangue of actinolite is unique. Actinolite, together with axinite and other borosilicates, however, occurs as a gangue material in certain Tasmanian copper deposits.[a] The explanation advocated for these is essentially similar to that given above.

CAPE MOUNTAIN.

Cape Mountain forms the promontory fronting Bering Strait at the westernmost extremity of the American Continent. On the eastern flank of the mountain are a few widely scattered houses, which form the settlement known as "Tin City." Tin City is 110 miles by steamer route from Nome, with which it is connected by telephone.

GENERAL GEOLOGY.

Granite.—Cape Mountain consists of a granite mass, which has invaded a series of crystalline limestones of Carboniferous age. (See fig. 5.) The limestones are lying nearly flat, but with a slight easterly dip, and extend eastward nearly to the mouth of Baituk Creek, where they are faulted against the slates of the York area. At the cape the limestones dip in toward the granite. Locally along the contact, as on Village Creek, the limestone is crumpled and turned up at high angles—phenomena ascribable to the dynamic activity of the intrusive. Some fine-grained olivine basalt dikes, vesicular and in part filled with calcite amygdules, cut both granite and limestone. They are without doubt by far the youngest rocks of the area.

The granite of Cape Mountain is of a coarse-grained gray type, containing numerous large porphyritic feldspars, either microcline or orthoclase, commonly an inch or so in length. Quartz, acid plagioclase, and biotite comprise the remaining essential constituents. The quartz is prevailingly smoky. Along the contact with the limestone the feldspars are locally aligned with their longer axes parallel. More commonly, however, the granite is fine grained along its margin, and fluorite, tourmaline, and white mica appear. Pegmatite blebs

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[a] Weed, W. H., Copper mines of the world, New York, 1907, p. 171.

containing tourmaline are common in the body of the granite. Dikes and sills of granite or granite porphyry cut the surrounding rocks.

Detailed mapping of the contact between the granite and limestone has shown that the underground extension of the granite surface dips steeply to the east on the east side of Cape Mountain, but that on the north side it slopes gently to the north beneath the limestone capping. Erosion has left some thin wedgelike remnants resting upon the granite surface. (See fig. 6.) Some limestone masses were broken off from the roof which covered the granite at the time of its intrusion and were partly submerged in the molten rock. An isolated limestone patch, which had this mode of origin, rests in the granite near the head of Lagoon Creek. Attention is drawn to these foundered blocks of limestone because if any ore occurs along their contacts it can have only a meager distribution. The dikes and sills, together with the limestone masses torn off at the time of intrusion, tend to produce a highly irregular contact surface between the limestone and the granite. This fact is of practical importance when the development of contact ore bodies is being considered.

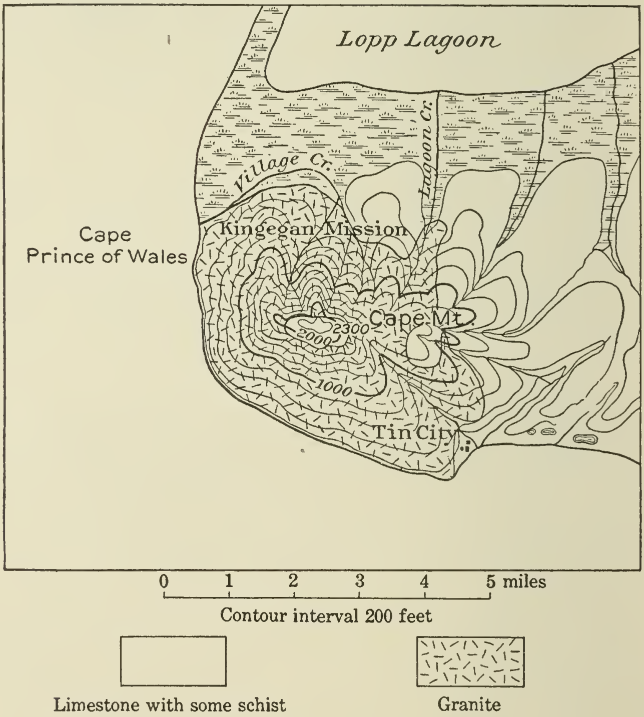

Fig. 5.—Geologic sketch map of Cape Mountain.

Contact phenomena.—The principal effect of the intrusion of the granite on the surrounding limestone has been to produce a coarse white marble, extending at a maximum 200 or 300 feet from the contact. Proximity to the granite contact is in many places indicated by a peculiar rough appearance of the limestone, due to the development of small patches of lime-silicate minerals, ordinarily invisible to the eye. These weather out in relief and give it a characteristic "shaggy" appearance near the granite. At other points delicate radial groups of tremolite appear on the weathered surfaces of siliceous phases of the limestone. A faint banding is also evident, due to the fact that the pure carbonate laminæ have been converted to calc spar. The siliceous bands in the limestone overlying the granite near the summit of Cape Mountain have been converted into wollastonite. At the contact on Bering Strait beds of almost solid wollastonite 2 or 3 feet thick inclose an alaskite sill 1 foot thick and extend 30 feet from the main granite mass.

Contact metamorphism involving an addition of material is of relatively rare occurrence and is confined mainly to the limestone adjoining the dikes and sills. On the Canoe claim an open cut exposes a sill 8 feet thick, consisting of the normal porphyritic granite of Cape Mountain. The upper 1½ feet, however, consist of coarse alaskite-pegmatite composed of orthoclase and quartz individuals 4 to 5 inches in length. Between the pegmatite and the porphyritic granite a zone of relatively fine-grained granite up to 6 inches thick intervenes, but no great regularity can be observed for this feature, as all three phases may be confusedly intermingled. The question whether the pegmatite did not represent a separate intrusion along the contact was considered, but as large quartz individuals with pyramidal terminations were found projecting from the pegmatite into the fine-grained granite, and as transitions are everywhere observable between the three phases, the conclusion was unavoidable that it was practically contemporaneous with the granite. Some tourmaline is of later origin and is developed along seams. This occurrence resembles the "stockscheider"—a peripheral zone of giant granite enveloping the stanniferous granite bosses of the Saxon Erzgebirge—and suggests Élie de Beaumont's observation[a] "that the peculiar

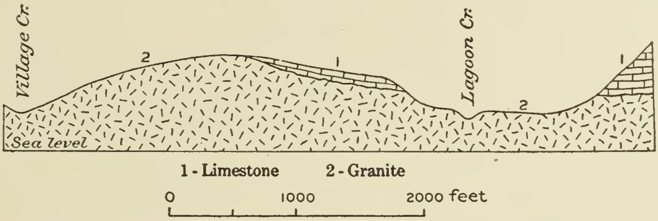

FIG. 6.—Geologic section across Lagoon Creek, Cape Mountain.

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[a] Cotta, B., Gangstudien I, Freiberg, 1850, p. 398.

cause of the coarsely crystalline character of the granite had acted mainly upon the marginal portion of the eruptive mass." The limestone overlying the pegmatite selvage is marmorized, and where in immediate contact has been converted into a heavy green finely granular rock. Under the microscope this proves to be a pyroxene-fluorite hornfels composed essentially of hedenbergite and fluorite, with accessory calcite and quartz. Scheelite and pyrrhotite occur in a few scattered grains. The association of a pyroxene hornfels with similar pegmatitic selvages is repeated at various other points on Cape Mountain. Near the Percy shaft the hornfels consists of hedenbergite, calcite, and scapolite, with accessory scheelite. The scheelite occurs in round, droplike grains embedded in calcite or intercrystallized with the pyroxene. It resembles titanite and cassiterite, but may be distinguished from the former by its positive uniaxial character and from the latter by its moderate birefringence (0.016). Inasmuch as scheelite is not commonly recorded as a contact-metamorphic mineral, the hornfels was submitted to E. C. Sullivan, of the United States Geological Survey, who verified chemically the presence of tungsten. The pannings from approximately 10 grams of rock were fused with Na_2CO_3, the fused mass was leached with water, the tungsten was precipitated with $HgCl_2$ as Hg_2WO_4, the mercury was expelled from the tungstate by heat, and the residue was examined by the reduction tests with Zn and Sn. The rock was also tested for chlorine by Doctor Sullivan and gave a strong reaction for this element, thus confirming the optical determination of the scapolite.

ORE DEPOSITS.

Cassiterite probably occurs in three ways at Cape Mountain—(1) in tourmalinized peripheral portions of the main granite mass and in tourmalinized granite dikes; (2) in contact-metamorphic rock, and (3) in veins in granite and as an impregnation of the adjoining wall rocks. From experience in developed tin regions it appears that the first type of occurrence is apt to be of low grade, and that the second is an unlikely source of tin ore. The occurrences on Cape Mountain indicate that the Alaskan deposits will prove to be no exceptions to this rule. The third is the normal type the world over, and has yielded the deepest and most productive mines.

At Cape Mountain no practical distinction is made between the first and the second modes of occurrence. The largest amount of prospecting has been done along the granite-limestone contacts because some rich pockets of tin ore have been discovered in tourmalinized granite along the contact and because of the distinctive character of the contact-metamorphic rocks (pyroxene hornfels). It can not be positively asserted that cassiterite occurs in the contact-metamorphic rock (in fact, all observations have been to the contrary), but it is not improbable that some tin ore may occur in the tourmalinized limestone adjoining tourmalinized granite.

Some of the dikes cutting the limestone show margins which are strongly tourmalinized and considerably impregnated with cassiterite. Large masses of bluish tourmaline occur, and these carry rich pockets of tin ore of a light-brownish color. The limestone adjoining the dikes has here and there been converted into coarse white spar, in which numerous prisms and columns of tourmaline are embedded. Where tourmalinization has been complete it may be difficult to distinguish tourmalinized limestone from tourmalinized dike rock. The tourmalinization, either of granite or limestone, however, appears to be purely local and erratic in occurrence. Furthermore, the tourmaline rock, although, as already stated, locally rich in cassiterite, is in general quite barren.

Along the periphery of the main granite mass local tourmalinization of the granite has taken place, accompanied by an introduction of cassiterite and pyrite. The pyrite has largely been oxidized, and in this way heavy red porous masses, consisting chiefly of iron oxide, with tourmaline and cassiterite, have been produced.

The contact rocks adjoining the large granite stock and some of the granite sills have been prospected at a number of places. A heavy green rock, showing in places finely disseminated pyrrhotite, has been regarded as tin ore, but microscopic and chemical analysis fail to reveal any tin. The green rock is locally known both as " greenstone " and as " tinstone." It is a finely granular rock, consisting of pyroxene, probably hedenbergite, and fluorite in equal proportions. This rock is well exposed in a cut on the Canoe claim, where a few feet of it directly overlies a granite sill, 8 feet thick. At other points on Cape Mountain, notably one-half mile north of the Lucky Queen property, the pyroxene is embedded in calcite. The pyroxene, which is unusually well developed for a contact-metamorphic rock, is of brown color and does not look unlike cassiterite, especially cassiterite which shows a macroscopic cleavage. It is true that cassiterite has a more splendent luster, but the distinction is not one that carries conviction. Where the presence of tin is suspected in such rocks, only assays can give reliable information.

The statements regarding deposits of contact-metamorphic origin made for the Ear Mountain region are equally applicable to Cape Mountain. In addition, the highly irregular nature of the granite contact makes prospecting for such deposits difficult and would entail heavy—probably unwarrantable—expenses in mining them.

Up to the present time a single narrow quartz vein has been found in place, cutting the granite on the north side of Cape Mountain at an altitude of 1,850 feet. The vein is accompanied by some alteration to greisen and partial tourmalinization of the adjoining granite—changes characteristic of tin-bearing veins. At other points on Cape Mountain cassiterite, accompanied by tourmaline, is found as an impregnation of the granite adjoining slips or fault planes. This type of occurrence, in the opinion of the writer, holds out greater possibilities for the future of the district as a tin producer than the other two. Unfortunately, exploratory work has been mainly confined to the contact deposits.

DEVELOPMENTS.

At the time of visit two properties only were being actively prospected at Cape Mountain—those of the United States Alaska Tin Mining Company and the Bartels Tin Mining Company. The former property is situated near the summit of the mountain, on the north side. Developments up to the end of July, 1907, consisted of a shaft reported to be 22 feet deep, now filled with water, and a 7-foot tunnel, 270 feet long. The company has also erected a 10-stamp mill near the beach at Tin City. Four men were employed at the time of visit. The shaft is sunk on a quartz ledge, 1 foot thick, striking N. 45° W. (magnetic) and dipping 80° E. The tunnel, whose altitude at the portal is 1,600 feet, according to aneroid measurement, is driven in a direction S. 40° W. through hard, firm granite, and is expected to tap the ledge 250 feet below the collar of the shaft.

The principal development work by the Bartels Tin Mining Company has been done on the North Star property. Eight men were employed during the summer of 1907. The main tunnel, with its drifts and winzes, aggregated 750 feet in length. This tunnel is being driven to catch the granite-limestone contact at a depth of 100 feet below the workings of the Lucky Queen tunnel. About 400 feet from the mouth of the tunnel a band of granite, carrying numerous visible crystals of cassiterite, associated with some tourmaline, was encountered. The width of this band is about 18 inches. The granite is soft and iron stained. The succeeding 3 feet consists of hard gray granite with pyrite disseminated through it. This is succeeded by 15 feet of iron-stained granite. At the time of visit the 18-inch belt of rich tin ore had not been drifted on to prove its persistence. The drifts branching off from the main adit follow the contact of a large limestone block, which was evidently torn from the main limestone mass during the intrusion of the granite. In following this contact, which proved to be of a highly irregular nature, several winzes were necessary. A new tunnel, 67 feet below the North Star tunnel, is being run from the surface to connect with the lowest drifts reached by these winzes. The granite along the limestone contact is charged with numerous radiating groups of tourmaline prisms associated with iron oxide, and locally with pyrite and tin ore. Crushing and oxidation have taken place along the contact, and heavily iron stained gouge matter. a foot in thickness, has been produced. At points where the red clayey material is absent the granite is fresh and the progressive increase of fineness of grain as the contact is approached can be noted.

A considerable portion of the energies of the company has been expended on assessment work on the numerous claims which it holds on Cape Mountain.

On the Carlson & Goodwin property an adit 20 feet long has been driven along the contact of a horizontal limestone and a granitic dike. The dike sends small, irregular tongues into the limestone, and the ends of these tongues have been completely converted into blue tourmaline rock. The limestone has been rendered coarsely crystalline, but evinces no other change. Rock from the dump, however, shows that locally an intense tourmalinization was produced. No stanniferous rock was seen in place.

On the northwest side of the mountain, on Village Creek, some drill holes have been put down to the granite contact, but the results are not known.

BROOKS MOUNTAIN.

Brooks Mountain, the dominant peak of the York Mountains, lies in the watershed of the Bering and Arctic drainages. It is easily accessible from the coast by way of Lost River, a distance of 9 miles. The mineral deposits are of contact-metamorphic origin, and though no cassiterite-bearing rock has been discovered on the mountain, yet the character of the mineralization here allies it to that of the tin region, of which Brooks Mountain is geographically a part.

An intrusive granite mass, 2 miles long by two-thirds of a mile wide, forms the southern flank of the mountain. The granite is characterized by the presence of numerous large porphyritic orthoclase crystals, commonly an inch in diameter, and large idiomorphic crystals of smoky quartz exceeding peas in size. The matrix consists of a coarsely granular assemblage of orthoclase and subordinate oligoclase ($Ab_{80}An_{20}$), with quartz and biotite in small amounts. The rocks surrounding the granite are chiefly limestones of the Port Clarence formation, and are highly crumpled throughout much of the region. Along the periphery of the granite they have been marmorized, and an extensive variety of contact-metamorphic minerals have been produced in the immediate vicinity of the contact.

At the west end of the granite stock a horizontal pegmatite about 8 inches thick traverses the white marble. It consists of orthoclase, quartz, and biotite, generally segregated in separate masses, the biotite in plates one-half inch in diameter forming selvages 1 to 2 inches thick. Thin sections cut from equidimensional portions of the pegmatite show, in addition to the three constituents already named, a small amount of plagioclase, some faint-colored bluish-green mica, accessory corundum, and probably topaz. The structure is allotriomorphic granular. The pegmatite is overlain by 1 foot of finely granular, heavy green rock, resembling that adjoining the pegmatite selvages on Cape Mountain. This rock is composed of vesuvianite, hedenbergite, and fluorite in approximately equal proportions.

Vesuvianite is the commonest mineral in the metamorphic aureole of the granite mass. Along the headwaters of Yankee Creek the impure crumpled Port Clarence limestone is brought into contact with the intrusive stock, and a thorough recrystallization has ensued. Crystallographically perfect vesuvianite in prisms up to three-fourths inch in length occurs scattered in great profusion through a matrix of coarse white calc spar. The vesuvianite is noteworthy as containing 0.88 per cent B_2O_3.[a] Where this mineral has not individualized into large crystals the metamorphosed rock consists of a fine equigranular aggregate of vesuvianite, calcite, and possibly garnet, interspersed with minute plates of phlogopite. The growth of the large crystals has produced a clarification, as it were, of the carbonate rock, and the boron content of the vesuvianite shows that this process was promoted by pneumatolytic agents. In this connection it is significant that an energetic tourmalinization of the granite has taken place at a number of points in the vicinity of this portion of the contact.

At the west end of the Brooks Mountain granite mass a prospect trench discloses a body of argentiferous galena ore, occurring 20 feet from the granite contact in a coarsely crystalline white limestone. The strike of the ore body, as revealed in the open cut, is N. 15° W. (magnetic), and the dip 65° toward the granite. A thickness of 3½ feet of solid ore is exposed, consisting of galena strongly admixed with a lustrous black zinc blende which, as analysis shows, contains 19 per cent of ferrous iron. Some pyrrhotite is also present, but this mineral is comparatively rare. Where any gangue mineral is visible it consists of fluorite. The ore body is frozen to both walls. The hanging wall shows a belt of finely granular fluorite several inches thick, succeeded by extremely coarse calcite containing scattered crystals of diopside and some galena. The grain of the calcite decreases away from the ore body. A thin section of rock taken from a point near the hanging wall is composed of calcite, fluorite, diopside, calcic plagioclase (Ab_2An_3), an unknown positive uniaxial mineral, and a small amount of colorless mica, with sporadic grains of the ore minerals. Assays of the ore made in Nome yielded 34 per cent of lead

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[a] This determination was made by Prof. Edgar F. Smith, of the University of Pennsylvania, according to two new methods for the estimation of B_2O_3 that he has recently discovered.

and 11 ounces of silver per ton. Other assays were reported to give ore values ranging from $17 to $44 per ton.

In the vicinity of the galena prospect there is some contact-metamorphosed limestone containing a fibrous green magnesia-iron boron mineral (ludwigite?) intercrystallized with galena. Loose masses of paigeite hornfels are also present. Some rock containing abundant honey-yellow crystals of chondrodite and numerous minute octahedra of spinel, embedded in a mesostasis of calcite with accessory magnetite, occurs near by.

In the same general locality some contact masses of vesuvianite have been prospected for nickel. The vesuvianite is in part finely granular and gives the rock a general green color. This feature and the unusual weight of the rock (that is, compared to quartz) doubtless caused the nickel prospecting. No indications of nickel are present, and it may be added that such a mode of occurrence is totally unknown for nickel. On microscopic examination small amounts of calcite, deeply pleochroic biotite, and hedenbergite are found associated with the vesuvianite.

In the canyon below the galena claim some assessment work has been done on a showing of contact-metamorphic minerals near the granite contact. The deposit is interesting from a scientific standpoint, inasmuch as a hitherto unknown boron-tin mineral has been discovered in it, but nothing of great commercial importance has been found here. The minerals comprise brown garnet, showing rhombic faces, green or yellowish-green vesuvianite, and abundant magnetite closely associated with the new mineral—a magnesia-iron tin borate which has been named hulsite.[a] These various minerals are all included in a matrix of coarse white spar (Pl. III, *B*). On account of the low percentage of tin in hulsite (approximately 10 per cent) the deposit can have no economic value.

At the head of the same canyon other contact-metamorphic deposits have received attention. Here, at an altitude of 2,000 feet, a small prospect hole exposed a mass of metamorphic minerals occurring in a white marble a few feet from the granite contact. Tourmaline, fluorite, calcite, arsenopyrite, brilliant black sphalerite, pyroxene, and axinite occur confusedly intergrown. The ore body is 4 feet thick and penetrates the marmorized limestone in irregular tongues a few inches thick. Some galena was noted in the ends of these tongues, which were examined microscopically and found to consist almost exclusively of monoclinic pyroxene. A few hundred feet north of this occurrence the pure white marble gives way to a highly metamorphosed impure limestone, consisting essentially of vesuvianite, calcite, biotite, and accessory tourmaline. Some of this rock contains sphalerite

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[a] Am. Jour. Sci., 4th ser., vol. 25, 1908, p. 323.

and other sulphurets, which on oxidizing give it a gossan appearance. High gold assays were claimed from this type of rock. Ledoux & Co., of New York, report on an assay sample submitted by the Survey: "Gold, trace; silver, 0.23 ounce."

On the north side of Brooks Mountain, at an altitude of 1,850 feet, is a small galena prospect. The galena occurs in a gossan, the skeleton of which consists of tourmaline. The iron oxide of the gossan contains lead and traces of bismuth, the lead probably as carbonate and the bismuth as oxide.

LOST RIVER.

LOCATION.

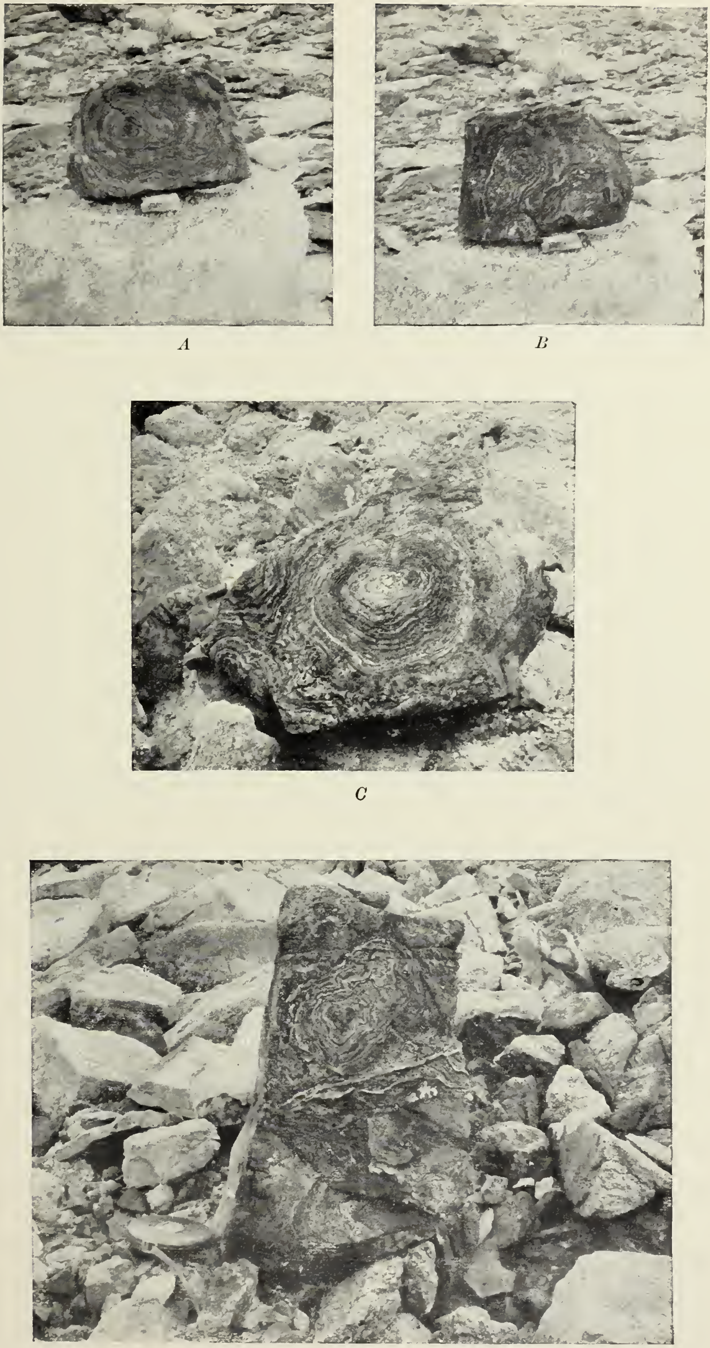
Lost River is a small stream rising in the heart of the York Mountains in the western part of Seward Peninsula. It flows southward into Bering Sea through a comparatively broad and open valley, except for a short stretch near its mouth, where it flows in a narrow canyon. It has a total length of 9 miles. The region is nearly destitute of vegetation, even Arctic mosses being scarce. The tin prospects are on Cassiterite Creek (see fig. 7), a branch of Lost River, 6 miles from the coast, and are easily accessible by a good wagon roadway. A tungsten-silver prospect, a copper prospect, and some galena prospects are also situated in this region.

GENERAL GEOLOGY.

The rocks.—The general geologic features of the region are simple. The bed rock consists of the Port Clarence limestone, dipping northward at an angle of 20°. Near the head of Cassiterite Creek the limestone is intimately banded with argillaceous laminæ, and intensely crumpled (Pl. II, *B*). Locally the formation is fractured and brecciated, and shear zones of white marble have been formed.

On Tin Creek, another tributary of Lost River, a small granite boss, a third of a mile in diameter, is intruded into the limestone. The granite is a medium-grained aggregate of feldspar, quartz (which is partly idiomorphic, smoky, and conspicuous), and scattered foils of biotite. The principal effect of this intrusion has been to marmorize the surrounding limestone, though locally some large masses of contact-metamorphic minerals have been formed.

A considerable number of vertical quartz porphyry dikes pierce the limestone, but only one has been found extending into the granite area. They are fairly persistent, and can be traced for several miles across the country. They are not all strictly contemporaneous intrusions, as certain dikes have been found to intersect each other. The quartz porphyries are light-colored rocks containing small glassy quartz and feldspar crystals embedded in an aphanitic matrix. The



A

B

C

D

A. ORBULE PRODUCED BY CONTACT METAMORPHISM.
B. REVERSE SIDE OF ORBULE SHOWN IN *A*.
C. MAXIMUM ORBULE; DIAMETER, 8 INCHES.
D. IRREGULAR ORBULES.

main tin prospects of the region occur in a few highly altered dikes of this character, but several of the other dikes have received separate names and have been more or less prospected, on what encouragement, however, it is difficult to understand. They are usually unmineralized, except for sporadic cubes of pyrite, and there is no known reason why they should become tin bearing in depth.

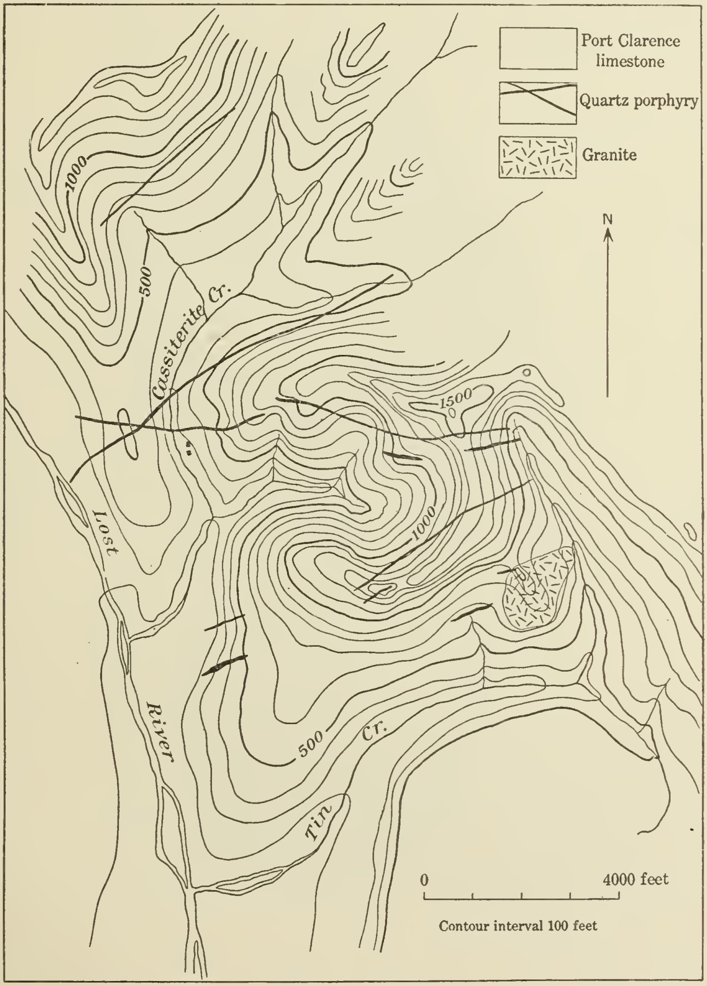


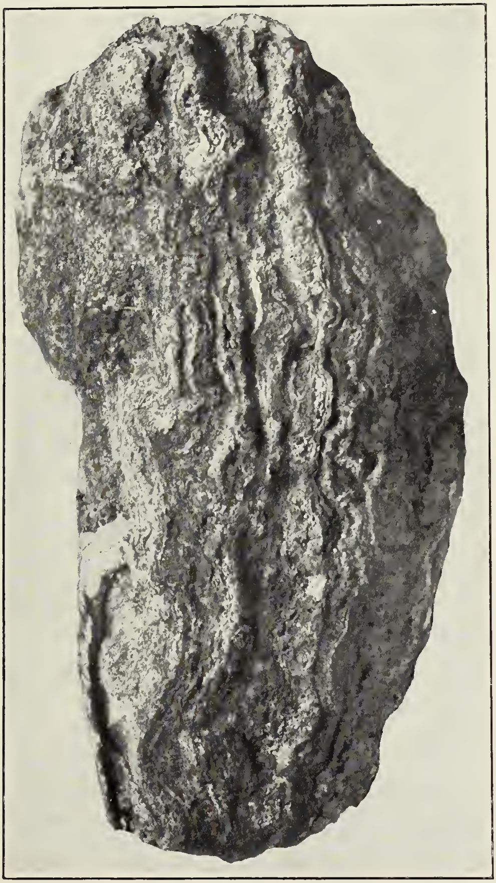
FIG. 7.—Geologic sketch map of Cassiterite Creek and vicinity. Topography by Adolph Knopf. Elevations determined by aneroid barometer.

Orbicular contact metamorphism.—The limestone surrounding the granite boss of Tin Creek has been converted into a coarse white marble. Near the contact loose blocks showing orbicular forms are common (Pls. IV, V, VI, *B*). The orbules are composed of an alternating succession of concentric black and white bands, commonly a millimeter or so in breadth. As shown in the photographs, the orbicular structure is brought out in detail by the etching action of the weather. Many of the sections through the orbules are perfect circles, a maximum diameter of 8 inches being noted, but elliptical forms, due to the interference of contiguous orbules, are common. In some places small orbules occur in the outer bands of large orbules and cause a wrinkling of the even banding. Where several small independent orbules have formed around closely spaced centers highly intricate structure resembling that of contorted gneiss has been evolved.

The minerals composing the orbules, named in their order of abundance, are fluorite, hornblende, vesuvianite, plagioclase (Ab_3An_7), and magnetite. The hornblende is a deep-colored variety, the pleochroism ranging from brown to strong greenish blue. The vesuvianite has a tendency to form radial groups of short, stout columns. Under the microscope the banded structure is not as distinctly apparent as would be expected from inspection of the weathered surface of the orbules. The light-colored bands consist of mutual intergrowths of fluorite and plagioclase; the dark bands consist of fluorite with hornblende or vesuvianite, or with both together, and commonly some magnetite. The presence of fluorite in both dark and light colored bands causes them to contrast less emphatically under the microscope than they do macroscopically. Examined in thin section the central portion of one of the orbules was found to consist of calcite anhedra in which are embedded vesuvianite, fluorite, and green amphibole inclosing considerable magnetite. This central area is surrounded by a ring of magnetite. Other centers are composed chiefly of fluorite and vesuvianite with intergrown hornblende. An unusual type of orbule is one composed of garnet, pyroxene, and fluorite, with narrow black bands of magnetite.

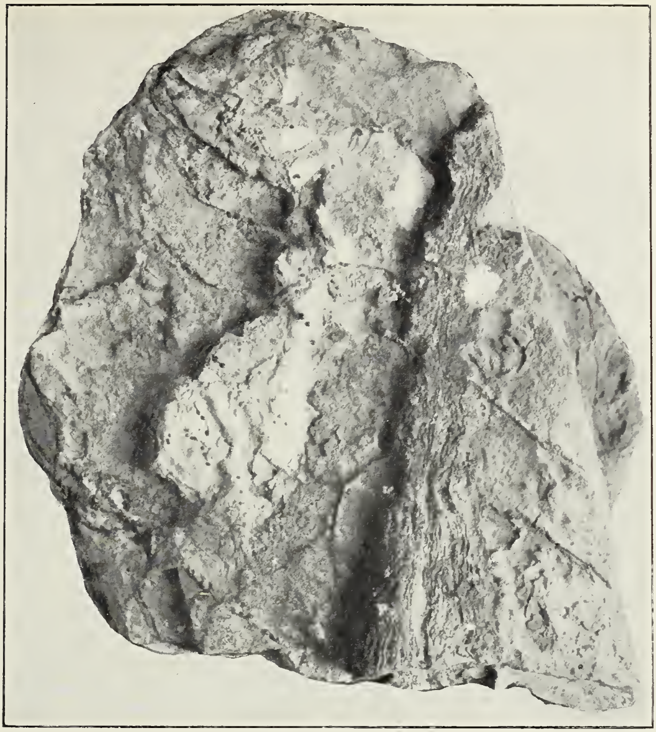
A single exposure outcropping beneath the talus near the granite-limestone contact throws light on the genesis of these remarkable forms. Curious veins, symmetrically banded, traverse the marmorized limestone in irregular fashion. The bands are only a fraction of a millimeter in thickness and simulate the sinuous flow lines of certain acidic volcanic rocks (Pl. V). Small tongues, a few inches in length, project into the marble, and these also are symmetrically banded. In irregular expansions of the veins orbicular structures have been developed (Pl. VI, *B*). The veins are composed of fluorite and calcic plagioclase (Ab_1An_2), with pyroxene, green mica, hornblende, and accessory arsenopyrite, cassiterite, and scheelite. They therefore resemble the orbules in mineralogical constitution to a considerable extent.

The orbicular material is cut by quartz porphyry, thus fixing the period of its formation, although not very closely. The only quartz porphyry dike penetrating the granite shows strong marginal chill-



BANDED VEIN; A SUPPLY DUCT FOR THE ORBULES.

Natural size.



A. BANDED APOPHYSIS FROM GARNET-VESUVIANITE MASS ON TIN CREEK.

Natural size.

B. ORBULES IN MARBLE MATRIX, SHOWING MODE OF ORIGIN.

ing, indicating, therefore, a considerable interval between the intrusion of the granite and the injection of the dikes. How nearly contemporaneous were the solidification of the granite and the metamorphism is an open question.

A mass of metamorphic minerals 50 feet wide is exposed on the bank of Tin Creek, 1,000 feet from the visible contact of the granite and limestone. It consists of solid masses of radial and arborescent vesuvianite and of brown garnet showing dodecahedral faces. The microscope reveals in addition small amounts of interstitial fluorite and calcite and accessory pyroxene, hornblende, and plagioclase. The dark mass of metamorphic minerals has injected apophyses, as it were, into the adjoining limestone (Pl. VI, *A*). These are arranged in black and white bands, a fraction of a millimeter in thickness. The microscope shows that these apophysal veins are composed of fluorite, strongly pleochroic from brown-green to blue-green hornblende, vesuvianite, and calcite, with accessory magnetite and arsenopyrite. These features ally this occurrence with the orbicular contact metamorphism and suggest that the heavy vesuvianite-garnet masses were produced by magmatic solutions traveling outward along fissures in the limestone.

Forms similar to the orbicular structures have not previously been recorded. Trüstedt[a] has recently described some curious occurrences ("Erzschlauche," he terms them) from Pitkaranta, in Finland, which in their essential aspects resemble the banded veins serving as the supply ducts for the Alaskan orbules. Cross sections of the ore arteries resemble sections through the orbules and, moreover, show a similarity in mineralogical constitution and similar alternating bands composed of magnetite and fluorite-vesuvianite with sporadic garnet. The explanation advanced for the ore arteries, which anastomose through a limestone, is that they are crustification structures produced by juvenile waters subject to rapid changes in composition and temperature. The circular pipes along which the deposition took place were produced by the corrosive action of earlier solutions. This hypothesis does not fit the Lost River phenomena. The mode of growth of the orbules—outward from centers—their common interferences, and their position adjoining the banded veins preclude an origin by crustification. Their essential similarity to the banded veins and their parasitic habit show that the two features are identical phenomena, which, as already indicated, are allied to the formation of the vesuvianite-garnet masses. The explanation which the writer would suggest for this related set of phenomena is that it was produced by magmatic emissions traveling outward under great pressure along fissures in the limestone; that the flow of the solutions was im-

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[a] Trüstedt, O., Die Erzlagerstätten von Pitkäranta am Ladoga-See: Bull. Comm. Geol. de Finlande, No. 19, 1907, p. 226.

peded; that at points of stagnation the wall rock was thoroughly permeated and a local intense metasomatism was produced. The solutions contained large amounts of fluorine, aluminum, silicon, iron, and sodium. The formation of fluorite (CaF_2) caused the expulsion of an equivalent quantity of CO_2 from the limestone and, owing to the absorption of this gas, the capacity of the solutions to dissolve lime was increased to a high degree.

It is probable that the channels of circulation were enlarged by this process and that the vein filling as now seen consists of minerals formed from the lime of the wall rock and fluorine, aluminum, silicon, iron, and sodium derived from the magmatic solutions. In such veins formed in limestone under conditions of high pressure and temperature it appears to be impossible to discriminate between metasomatically altered wall rock and the filling of the original channels of circulation. The banding was produced either by processes similar to those which have given certain igneous dikes their banded character or by phenomena similar to those operative in the formation of Liesegang's rings. If a drop of $AgNO_3$ solution be placed upon a gelatin plate impregnated with $K_2Cr_2O_7$ a series of concentric rings consisting of $Ag_2Cr_2O_7$ will be formed, becoming progressively wider spaced with increasing distance from the center. The explanation given by Ostwald[a] is that as the soluble silver salt diffuses outward a periodic precipitation of insoluble silver chromate will take place at the loci of supersaturation. Morse and Pierce[b] have investigated this phenomenon in some detail, using tubes, however, instead of plates, and have shown incidentally that gelatin is not essential to the production of the rings and bands. Among other substances employed were $FeCl_3$ and Na_2CO_3, and a recurrent evolution of CO_2 was noted. This reaction proceeds as follows:

$$2FeCl_3+3H_2O+3Na_2CO_3=3CO_2+6NaCl+2Fe(OH)_3.$$

When the attempt is made to fit this explanation to the natural conditions the problem becomes greatly complicated on account of the complex character of the solutions, the unknown state of combination of the various elements, and their different rates of diffusion. As abundant fluorine was present in the solutions, a reaction analogous to the preceding may be formulated as follows:

$$2FeF_3+3H_2O+3CaCO_3=3CO_2+3CaF_2+2Fe(OH)_3.$$

The fluorine was thus fixed as fluorite and the iron separated as magnetite or was taken up by the production of amphibole. Enough

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[a] Lehbruch allegemeinen Chemie, 2d., Band 2, Teil 2, p. 778.

[b] Zeitschr. physikal. Chemie, vol. 45, 1903, p. 589.

has been indicated to show that an explanation involving diffusion and supersaturation is at least as plausible as one involving crustification and is in closer harmony with the phenomena observed in the field.

CASSITERITE PROSPECTS.

Lodes.—At Tin Creek a few thin quartz stringers carrying cassiterite have been found in the granite. Collier[a] has shown that some pyritiferous granite from the same locality contains 0.3 per cent of tin. No cassiterite is visible in this granite to the unaided eye, so on account of the prevalence of sulphides he assumed that the tin occurs in the form of tin pyrites (stannite). A cut has been opened on this occurrence and shows a number of narrow bands of hard quartzose granite containing finely disseminated pyrites, chiefly of iron and arsenic. Under the microscope the rock is seen to be composed of quartz, topaz, and sericitized feldspar, with accessory pyrite, arsenopyrite, and cassiterite in small amount.

The principal tin prospects of the region are located on Cassiterite Creek, and occur in the quartz porphyry dike known as the Cassiterite lode. This dike is 6 to 10 feet thick and can be traced from the head of Tin Creek in a northwesterly direction to Lost River, a distance of 9,000 feet. Near Lost River the dike rock contains a multitude of angular limestone fragments and is really a limestone breccia cemented by quartz porphyry. The characteristic feature of the Cassiterite lode dike rock, where nonstanniferous, is the abundance of sharply defined quartz phenocrysts embedded in a white aphanitic matrix. Thin sections cut from the least-altered portions of the dike show numerous phenocrysts of quartz, orthoclase, and sodic plagioclase embedded in a cryptocrystalline groundmass. The nonlamellated feldspar is opaque from kaolinization, but the plagioclase is unaltered. Sporadic crystals of clear and limpid plagioclase lie inclosed in turbid orthoclase phenocrysts. Fluorite is common in the groundmass and patches of topaz occur also. More highly altered phases of the dike merely show quartz phenocrysts lying scattered in a matrix of scaly white mica. fluorite, and quartz. Along a portion of its course the white quartz porphyry dike has broken through an older dike, a gray feldspar porphyry, which is particularly conspicuous on account of the multitude of dull white phenocrysts that it contains.

The tin-bearing portion of the dike is 3,000 feet long, but the whole of this length can not be considered ore rock; intermittent barren stretches occur, and the ore is probably localized in irregular shoots. The limestone in the vicinity of the stanniferous portion of the dike

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[a] Collier, A. J., Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 229, 1904, p. 22.

is seamed with innumerable veinlets which reticulate the surface of the country rock in every conceivable direction (Pl. VII, *A*). These vary in thickness from a film's breadth to several inches. An energetic metasomatic alteration has accompanied the veinlets, and cassiterite is locally observed in them, but nothing in the nature of a stanniferous stockwork has been formed.

The tin ore found in the quartz porphyry dike is associated with irregular seams and stringers of quartz and lithia mica. Cassiterite occurs both in the stringers and as an impregnation of the altered dike adjoining the stringers. Where the veinlets are absent the quartz porphyry contains no cassiterite, and is hard and barren. Wolframite is commonly associated with the cassiterite and, though no actual tests have been made, it is probable that the tungsten content of the lode is as valuable as the tin. Pyrite and arsenopyrite accompany the tin ore and more rarely sphalerite and galena are found. Locally the dike rock contains some molybdenite. The commonest gangue mineral is fluorite, with zinnwaldite next in order of abundance. Thin sections show also the presence of topaz in radial aggregates. Where alteration has been most intense large drusy masses of cubical fluorite and mica occur, and from such localities magnificent specimens of cassiterite in black splendent crystals have been obtained. The usual type of ore, however, is a soft kaolinized porphyry, stained red with iron oxide, and impregnated with cassiterite, wolframite, and sulphides. The dike is intensely and irregularly slickensided and clay gouge is common. The limestone wall rock, however, is firm and hard. It is considerably impregnated with fluorite, which glows with a greenish light when struck with the pick. Thin sections of wall rock immediately adjacent to the dike show that it consists of fluorite and radial topaz, with some colorless mica. Cassiterite occurs to a small extent in the wall rock in narrow veinlets (1 inch thick) consisting of divergent columnar topaz. In the vicinity of these veinlets the fluoritized limestone contains patches of coarse fluorspar and rosettes of topaz.

A few hundred feet north of the Cassiterite lode is another quartz porphyry dike, known as the Ida Bell lode. It is about 35 feet thick on the summit of the hill between Lost River and Cassiterite Creek. The rock is dense and fine grained. In the vicinity of Cassiterite Creek quartz stringers an inch or so in thickness, carrying cassiterite with some wolframite, cut the dike, but along its eastern extension only sporadic cubes of pyrite can be seen. The alteration that is so characteristic a feature of the Cassiterite lode is conspicuously absent from the Ida Bell quartz porphyry dike. The petrographic similarity which a number of other quartz porphyry dikes in the Lost River basin bear to this dike has occasioned considerable useless prospecting.

A. RETICULATE SEAMING OF LIMESTONE IN VICINITY OF CASSITERITE LODE.

B. SURFACE EXPOSURE SHOWING OCCURRENCE OF FLUORITE-SILICATE ROCK ADJOINING VEINLETS IN LIMESTONE.

One mile north of the Cassiterite lode is another tin-bearing porphyry dike named the Dolcoath lode. It is from 2½ to 3 feet thick, strikes N. 50° E. (magnetic) and dips 65° NW. This dike differs from the two previously described both in its mineralogy and in the mode of occurrence of the tin ore. It is so highly altered and mineralized that its original igneous character is not everywhere readily apparent. Least-altered phases show a dark-gray fine-grained rock containing numerous dull feldspar phenocrysts and a few quartz crystals. The feldspars prove to be near labradorite in composition, and the groundmass is largely obscured by secondary minerals, such as tourmaline, quartz, pyrite, mica, chlorite, and others. Some movement has taken place along the walls of the dike, especially the hanging wall, forming a crushed zone 1 to 6 inches thick. The dike rock is heavily charged with arsenical pyrites and tourmaline and contains some cassiterite disseminated through it. Locally the dike has been converted into large masses of danburite containing radial groups of tourmaline and an abundance of arsenopyrite. Cassiterite is inclosed in these three constituents, but is visible only under the microscope.

The wall rock of the dike is the dense-textured banded argillaceous variety of the Port Clarence limestone. The calcareous portion has been converted into coarse white spar containing random prisms of tremolite; the argillaceous bands have been converted into matted aggregates of tremolite fibers. Finely crystallized cassiterite occurs embedded in the coarse calc spar and locally is extremely abundant. Topaz in square prisms is found in the limestone to some extent. Cassiterite also occurs in the wall rock intimately intergrown with pocket-like masses of danburite, which is a calcium borosilicate related to topaz. The danburite is of light pinkish-gray color, with a peculiar vitreous greasy luster, and occurs as rude ill-defined columns in rough radial arrangement. Examination of the danburite-cassiterite ore in thin section shows that the cassiterite, which is finely idiomorphic, lies embedded in the danburite, and contains innumerable microlites of tourmaline. The danburite incloses some small patches of calcite, and may, like the cassiterite, inclose great numbers of minute tourmaline prisms. These bands of wall rock, which carry tin ore and show marmorization with accompanying development of danburite, topaz, and tremolite, occur on both foot and hanging walls of the dike, though nowhere more than 6 inches thick. Tremolite, however, persists to great distances from the dike, though in lesser abundance. Arsenopyrite has apparently replaced the wall rock to some extent also, as solid lumps of it containing only tremolite fibers have been found. The association of danburite and cassiterite is unique in the literature of tin deposits. To establish the identity of the danburite beyond question the following approximate partial analysis was made by W. T. Schaller on the purest material that could be obtained:

Analysis of danburite from Dolcoath lode, Lost River region.

SiO_2	47.54
Al_2O_3 Fe_2O_3	3.43
CaO	21.02
MgO	1.57
B_2O_3	[a]24.03
	97.59

Specific gravity, 2.98.

Developments.—At the time of visit five adits had been driven on the Cassiterite lode, three of which were open and could be examined. Tunnel B, 260 feet above Cassiterite Creek, was 180 feet long. The tunnel follows the southern margin of the dike, and is partly in limestone. At 45 feet from the mouth a drift has been run 10 feet to the north, crosscutting the lode. Tunnel A, 1,170 feet above the creek, was 80 feet long. The dike is soft and can be augered, so that an advance of 4 feet a day (single shift) is easily made. Both these adits are on the east side of Cassiterite Creek. Tunnel E, driven on the Cassiterite lode 10 feet above the creek level on the west side, is 100 feet long. A crosscut 9 feet long has been driven 50 feet from the mouth of the adit. The Ida Bell dike has been explored by an adit 55 feet long, at the end of which a winze 69 feet deep was sunk. This is now filled with water.

A few hundred feet south of the Cassiterite lode some open cuts and adits, now caved in, were opened on a porphyry impregnated with cassiterite. No surface croppings of this porphyry body are visible, for the porphyry is buried under the mantle of slide rock covering the steep slopes of the region. A shaft 50 feet deep was sunk on this occurrence, but was flooded at the time of visit. A number of open cuts have partly exposed some thin but rich quartz veinlets in the limestone. A shaft reported to be 18 feet deep was sunk near such a vein on the Jupiter claim, and a drift 44 feet long was run to the ledge, but both were also under water.

The developments on the Dolcoath dike consist of four cuts opened at intervals along a length of 3,000 feet. An assay of ore from one of the crosscuts was reported to have yielded 1.15 per cent of tin.

Seaming of the limestone.—The most striking feature in the vicinity of the Cassiterite lode is the vast multitude of veinlets that interlace the limestones in every direction (Pl. VII, *A*). The area thus affected extends for 1,000 feet or more on both sides of the stan-

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[a] Two determinations made with concordant results by Messrs. Chapin and Wherry under the direction of Prof. Edgar C. Smith.

niferous portion of the dike. On the basis of dominant mineralogical composition five types of veinlets can be discriminated—fluorite-amphibole, plagioclase-fluorite, zinnwaldite-topaz, topaz-fluorite, and tourmaline-mica. The pure types occur, but innumerable intermediate and transitional forms are found also.

Veinlets (Pl. VII, *B*), only one-half inch thick, consisting of fluorite and radial amphibole, are paralleled on both sides by altered wall rock, 2 inches wide, sharply delimited against marmorized limestone containing minute fibers of tremolite. The wall consists of fluorite, amphibole, vesuvianite, and green mica irregularly intergrown. Where embedded in fluorite the amphibole is a deep-colored variety, pleochroic in tones of brown-green and blue-green.

Allied to the veinlets just described are dense white veinlets consisting essentially of fluorite and plagioclase. Locally they contain hornblende and scattered grains of pyrite and arsenopyrite. They are inclosed by dark-green rock, which is very delicately banded by thin white bands running parallel to the central veinlet. The larger bands are a millimeter in width, but the most of them are narrower, and some are as narrow as 0.1 millimeter. These features are most strikingly apparent on weather-etched surfaces. Small seams branching from the central veinlet cut across the banded rock. The metasomatically altered wall rock is thus elaborately banded at but few places; more commonly it is a structureless green rock. In thin section the central veinlet is seen to be composed of an intimate intergrowth of fluorite and calcic plagioclase (as calcic at least as Ab_1An_1), with scheelite as an accessory mineral. The inclosing rock is formed of fluorite, hornblende, and vesuvianite, but green mica, pyroxene, and calcic plagioclase also occur, and arsenopyrite and cassiterite are present as rare accessories. The hornblende and vesuvianite are prone to form small radial groups. The narrow white bands are composed of intergrowths of fluorite and plagioclase. The macroscopic appearance of the banded rock immediately recalls the orbules and banded veins of Tin Creek, and this external resemblance is confirmed by the similarity of mineralogical constitution as revealed by the microscope. The chemical origin of the banding is here more obviously apparent.

Veinlets of zinnwaldite up to 1 inch in thickness are common in the limestone. Under the microscope the zinnwaldite forms radiating fanlike groups diverging from the vein walls. The mica is dirty greenish and somewhat pleochroic at the points of attachment. Elsewhere it resembles muscovite. Some topaz occurs as an interstitial filling, and cassiterite and wolframite are rare accessory minerals. In the specimen examined optically the wall rock is a cryptocrystalline limestone exhibiting only a feeble alteration. Others, however, show an energetic fluoritization and notable increase of granularity. An analysis of the zinnwaldite has been made by W. T. Schaller[a] in the laboratory of the Survey, and is quoted here to illustrate the elaborate composition of this mica.

Analysis of zinnwaldite in limestone near Cassiterite lode, Lost River region.

SiO_2	46.80
Al_2O_3	24.50
Fe_2O_3	.50
FeO	6.35
MnO	1.38
CaO	.24
Na_2O	1.73
K_2O	9.20
Li_2O	3.73
H_2O	.88
F	8.63
	103.94
Less $O=2F$	3.63
	100.31

Topaz-fluorite veinlets, carrying cassiterite and tabular crystals of wolframite, have produced both fluoritization and topazization of the adjoining limestone.

On the south side of the Cassiterite lode tourmaline veinlets are common in the limestone, though no tourmaline occurs in the tin ore of the dike rock. The cause of this peculiarity is not known. This type of veinlet is composed of white mica, blue tourmaline, and fluorite. Some carry visible cassiterite, but these are rare. Microscopic examination of a stanniferous veinlet (one-half inch thick) showed that the cassiterite is intergrown with scheelite, calcite, and mica (zinnwaldite?) and embedded in a gangue of mica, tourmaline, and fluorite. The limestone adjoining the tourmaline stringers has been converted into a confused intergrowth of green and indigo-blue tourmaline, fluorite, and magnetite, with accessory calcite, vesuvianite, green mica, and amphibole, forming a rock indistinguishable, texturally and mineralogically, from the contact-metamorphosed limestone of Ear Mountain.

A feature allied to the seaming of the limestone by the veinlets is found in an outcrop on the creek 200 feet below the Cassiterite lode, in which a zone of brecciated limestone has been recemented by various dark-colored minerals which here and there form large radial groups 3 to 4 inches in diameter. The cement or binding material when examined optically is found to consist chiefly of blue-green hornblende, vesuvianite, calcic plagioclase (Ab_1An_2), fluorite, minor amounts of calcite, and accessory scheelite.

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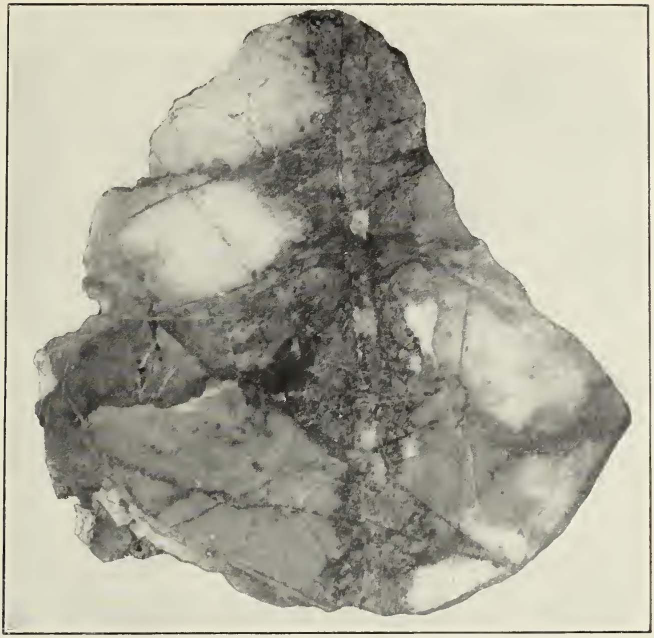
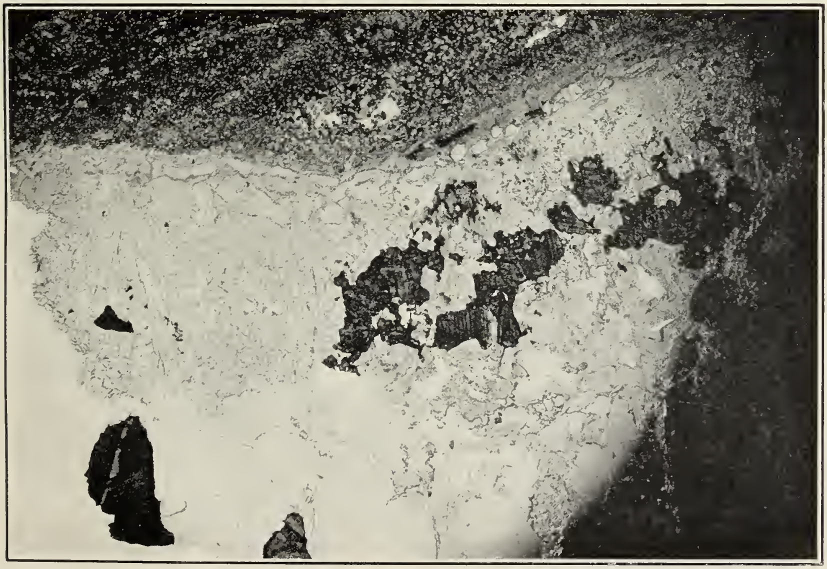
[a] Am. Jour. Sci., 4th ser., vol. 24, 1907, p. 158.



A. POLISHED SURFACE OF SEAMED LIMESTONE SHOWING INTENSE METASOMATISM ACCOMPANYING THE VEINLETS IN LIMESTONE AND NUMEROUS SUBSIDIARY VEINLETS BRANCHING FROM MAIN VEINLET.



B. THIN SECTION OF CASSITERITE ORE.

Magnification 12 diameters. Radial topaz diverging from vein wall.

To sum up briefly: In spite of the diversity of mineral composition of the various veinlets it is found that all are accompanied by similar intense alterations of their wall rocks (Pl. VIII, *A*). They appear to be of practically synchronous origin, except, perhaps, the tourmaline veinlets, and the smaller seams represent leakages along subsidiary fractures. A more complete interchange of material between wall rock and solution was apparently possible in the minor seams, for vesuvianite and garnet appear in them, whereas these minerals occur only in the metasomatically altered wall rock of the larger veinlets.

Cassiterite and wolframite quartz veins.—It is a notable feature that, although the quartz stringers cutting the porphyry dikes contain cassiterite and wolframite together, those cutting the limestone contain either cassiterite alone or wolframite alone, and in large proportions. Veinlets of such diverse composition occur not many hundred feet apart. They average only a few inches in thickness and, so far as is now known, 30 or 40 feet in length.

The cassiterite-quartz veins, while rare and of no great persistence, are extraordinarily rich in tin. Cassiterite, complexly twinned, occurs in crystals up to an inch in size. The predominant gangue mineral is quartz, with which are associated subordinate amounts of fluorite, feldspar, and white mica. The cassiterite is concentrated near the sides of the vein, which is frozen to the wall rock. Locally a thin band, one-eighth inch thick, of delicate radial topaz intervenes between the quartz gangue and the altered wall rock. Thin sections cut from this portion of the ore show groups of topaz prisms diverging from the wall of the vein (Pl. VIII, *B*). Closely associated with them are fluorite, white mica in well-defined plates, quartz, and cassiterite. The wall rock consists of a fine-grained aggregate of fluorite, topaz, and mica. Farther away from the vein the limestone is marmorized and transfixed with tremolite needles. The filling of the veinlets branching off from the cassiterite-quartz vein is not quartz, but is chiefly white mica. In the country rock adjoining the cassiterite-quartz vein, veinlets consisting essentially of white mica and lamellated plagioclase are common, and some of these are metalliferous. In their central portions they carry small amounts of galena, chalcopyrite, pyrrhotite, and sphalerite. The wall rock adjoining these veinlets, which average perhaps one-fourth inch in thickness, is altered to fluorite and aggregates of scaly green mica.

Some quartz stringers carrying considerable wolframite have been found cutting the limestone. The gangue material is dominantly quartz, but fluorite, white mica, and albite also occur. The altered wall rock consists of fluorite, green-blue hornblende, vesuvianite, green mica, and garnet, with scheelite and cassiterite as rare accessory minerals (Pl. IX, *B*). Sphalerite and chalcopyrite occur disseminated through the metamorphosed wall rock, though absent from the quartz veins themselves. The zone of metasomatism is sharply bounded by white saccharoidal limestone containing sporadic prisms of tremolite (Pl. IX, *A*).

The cause of the segregation of the cassiterite and wolframite into separate veinlets is not known. On the hill between Lost River and Cassiterite Creek a prospect trench has opened a tin-bearing veinlet 1 inch to 6 inches thick for a length of 30 feet. At one end the veinlet can be seen to pinch out. Throughout its length it is unusually rich in cassiterite and carries some wolframite and arsenopyrite. The gangue is composed essentially of topaz, fluorite, and zinnwaldite, arranged in a rudely banded structure. The middle band is the most distinctly defined, though only one-half inch broad, and consists chiefly of topaz imperfectly interlocking along a central line. The wall rock of this veinlet is highly altered and is impregnated to some extent with chalcopyrite, pyrite, and sphalerite. The study of this occurrence suggests that the simple quartz veins are due to a sort of differentiation from the primary solutions that deposited fluosilicates, and that, accompanying this change, a segregation of cassiterite from the wolframite may have taken place.

Metasomatic processes.—The Lost River occurrences throw some light on the metasomatism produced by stanniferous solutions acting on a nearly pure limestone. In the zone of most intense activity fluorine has effected a complex expulsion of the carbon dioxide with the production of abundant fluorite. On the assumption that the calcium remains constant and is combined as fluorite, this means a loss in volume of 34 per cent. This shrinkage appears to have been amply compensated for by the production of topaz, hornblende, vesuvianite, mica, plagioclase, and garnet, all of which involve an introduction of material, chiefly alumina and silica, with some FeO, Na_2O, K_2O, and Li_2O. Beyond the zone of fluoritization the limestone has been marmorized and some tremolite produced. The transition between the two zones is abrupt, and the difference of the amphiboles in them is a characteristic feature. The colorless tremolite, which is less abundant than the deep blue-green hornblende, has doubtless been produced by the recrystallization of impurities in the original limestone. Where the stanniferous solutions contained boron, alkali tourmaline has commonly been developed as a metasomatic mineral. At the Dolcoath dike the solutions appear to have been unusually rich in boron, and extensive danburitization has taken place, with accompanying development of cassiterite, tremolite, tourmaline, and topaz. Marmorization, too, has locally been intense, with the production of calcite individuals up to an inch in size.

The metasomatic processes outlined in the preceding paragraph are of a synthetic nature and have caused the formation of various

A. POLISHED SURFACE OF WALL ROCK ADJOINING WOLFRAMITE-QUARTZ VEIN.

Showing marked contrast between the marmorized limestone and the metasomatically altered limestone.

B. THIN SECTION OF WALL ROCK ADJOINING QUARTZ-WOLFRAMITE VEIN.

Magnification 32 diameters. Showing an intergrowth of hornblende, vesuvianite, and fluorite.

complex silicates, some of which, like topaz, danburite, vesuvianite, and hornblende, have not been described previously as alteration products in limestone adjoining fissure veins. Topaz, according to Rosenbusch,[a] is characteristic of the pneumatolytic contact zones of many granites. Danburite has recently been described as a constituent in some of the numerous contact-metamorphic deposits of Japan.[b] Vesuvianite is a typical contact-metamorphic mineral, and hornblende is common in the metamorphic aureoles of many granites. Tremolite, a common contact-metamorphic mineral, has, however, been recorded by Lindgren[c] from the Clifton-Morenci district as a metasomatic product in limestone adjoining fissure veins, and the unusual and significant character of this alteration has been pointed out. Tremolite, as has been shown, is one of the commonest products of the metasomatic activity of stanniferous solutions circulating in limestone, but only in the zone of least intense activity. To sum up briefly, the metasomatic alteration accompanying cassiterite veins in limestone, as exemplified by these Alaskan occurrences, is closely allied to contact metamorphism. The wall rock immediately adjoining the vein is characterized by the addition of material and the formation of fluo-, boro-, and alumino-silicates. This zone passes outward into one showing the features of simple thermal metamorphism—marmorization with the production of sporadic tremolite.

Wolframite-topaz lode.—A unique mineral deposit is exposed opposite the mouth of Tin Creek in an open cut on the ridge between Lost River and Left Fork. The surface indications show that the mineralization has taken place along a fault, running approximately east and west, which has brought two slightly dissimilar limestones into juxtaposition. Some brecciation is apparent along this line. The open cut shows stringers of ore occurring in a belt 1 foot thick, forming a stringer lode. The ore minerals consist of wolframite, galena, and stannite, and are embedded in a gangue of radial topaz associated with some deep-purple fluorite. The stannite is usually intercrystallized with the galena and is of a brown-black color. It reacts for tin, copper, zinc, iron, and sulphur. The topaz forms fine spherulitic aggregates, which may in places attain a diameter of half an inch, but as a rule are very small and are crystallized in delicate radial groups. The high specific gravity of topaz (3.5) gives the ore rock an unusually heavy weight. The surface ore is stained black by manganese minerals produced by the decomposition of wolframite. Some azurite is present also, and is doubtless derived from the copper

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[a] Mikroskopische Physiographie, vol. 1, pt. 2, Stuttgart, 1905, p. 139.

[b] Beiträge zur Mineralogie von Japan, No. 3, Tokyo, 1907, p. 102.

[c] Lindgren, W., Copper deposits of Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 176.

in the stannite. An assay[a] of a sample of this ore submitted by the Survey gave a return of 22.9 ounces of silver to the ton.

The gangue material was identified optically as topaz from its similarity to that associated with the tin ore on Cassiterite Creek. This determination was confirmed by an approximate quantitative analysis made by W. T. Schaller, with results as follows:

Analysis of topaz from wolframite-topaz lode, near Tin Creek.

SiO_2	30.27
Al_2O_3	54.66
CaO	1.16
MgO	Trace.
F	17.26
H_2O, alkalis	Not det.
	103.35
Less O=2 F	7.27
	96.08

The wall rock of the topaz lode consists of a dense cryptocrystalline limestone which shows no evidence of metasomatic alteration. The topaz lode is remarkable in two respects—it is the first recorded instance of topaz as a fissure-vein filling and as the gangue material of sulphide minerals. Topaz is common in the greisen adjoining cassiterite veins and in certain metasomatically altered quartz porphyry dikes, but has not hitherto been noted as a vein-forming mineral. It is regarded by Vogt[b] as distinctive of the cassiterite veins in contrast with the ordinary sulphide-ore veins (filons plombifères). The absence of metasomatic alteration in the limestone adjoining the topaz lode is noteworthy, but it will be recalled that some of the zinnwaldite-topaz veinlets in the vicinity of the Cassiterite lode show a similar lack of action on their wall rocks.

The stannite in the above-described wolframite-topaz lode is the only known verified occurrence of this mineral in the Alaskan tin region. Stannite is not a valuable tin-ore mineral, both on account of its relatively low tin content (30 per cent compared to 78 per cent in cassiterite) and its difficult metallurgical treatment. It is a rather favorite object of search with the prospector, chiefly because of the fascination which its unknown character exercises; and in consequence pyrite and pyrrhotite are commonly mistaken for stannite. It is, however, a mineral whose identity can be established only by careful chemical examination.

OTHER MINERAL DEPOSITS.

Alaska Chief property.—The Alaska Chief claim is situated about 4½ miles from Bering Sea, on Rapid River, the large western branch

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[a] Made by Ledoux & Co., of New York.

[b] Genesis of ore deposits; special publication of Am. Inst. Min. Eng., 1902, p. 666.

of Lost River. The workings are on a small gulch tributary to Rapid River. The country rock is a tough, fine-grained limestone of the Port Clarence formation, lying nearly horizontal. Locally the strata are buckled and show crushing in the crest of the buckles. A fault breccia 15 feet wide, consisting of small angular fragments of limestone cemented together by white calc spar, is exposed in the creek one-third mile west of the mine. Basalt, in the form of a narrow dike 1 foot thick, is the only other rock known to be in place in the near vicinity of the mine. A few thousand feet to the east a number of quartz porphyry dikes can be seen cutting the limestone.

The original shaft was sunk in a heavy body of porous red iron oxide containing galena, reported to be 12 feet thick. At a depth of 35 feet work was suspended. An adit 143 feet long driven 85 feet below the collar of the shaft encountered the same ore body 50 feet below the bottom of the shaft. The ore was still oxidized. About 7 feet of low-grade galena ore was exposed.

On the east side of the gulch a devious tunnel, about 600 feet in length, was driven to catch another body of galena indicated on the surface. The tunnel follows a zone of crushed limestone, bounded in many places by fine walls marked with striæ. The "ledge matter" consists of small fragments of limestone bound together by coarse calc spar, clay, and red iron oxide. No ore was encountered. The tunnel on the west side of the gulch was then commenced, and the ore body already mentioned was struck late in August, 1907.

Idaho claim.—A few hundred yards below the mouth of Tin Creek a copper prospect has been opened on the edge of the 15-foot bench fronting Lost River, and at the time of visit enough work had been done to expose the face of ore at this point. The deposit occurs in an irregular shattered zone in the limestone, 15 feet wide and including numerous horses of unmineralized limestone. The ore mineral is chalcopyrite, associated with abundant pyrrhotite (magnetic iron pryites), and occurs in a gangue of calcite, fluorite, and small fragments of slickensided rock. Some of the fluorite is rose-tinted and is locally known as ruby quartz. Stripping has shown that the same ore body extends at least 50 feet to the east, where a strong gossan has been uncovered. The relatively great width of the deposit, combined with the low chalcopyrite tenor and the abundance of pyrrhotite, reduces the copper percentage to a small figure.

On Tin Creek a galena prospect has been opened on some gossan croppings at an altitude of 1,100 feet, 800 feet above the bed of the creek. The deposit occurs in a fracture zone in the limestone, which has been coarsely recrystallized in the immediate vicinity, forming spar crystals up to an inch in size. The gossan consists of honeycombed masses of iron oxide containing abundant galena and numerous white and colorless crystals of cerusite (lead carbonate). It was planned to prove the value of this deposit during the winter of 1907 and 1908.

A small trench, 650 feet below the galena prospect, has been dug in the effort to locate the bed-rock source of some loose bowlders composed of arsenopyrite flecked with a small amount of cupriferous pyrite. Assays made in Nome are reported to have yielded $12 to the ton in gold. Some stibnite in a gangue of purple fluorite has been found in the saddle at the head of Tin Creek.

ORIGIN OF THE ORES.

The injection of the quartz porphyry dikes represents the final intrusive activity of an underlying granite magma, of which a portion is now exposed by erosion on Tin Creek. Fracturing of the dikes, accompanied by shattering of the adjacent limestone, took place after their consolidation, and an energetic mineralization ensued. As shown by the vein fillings and metasomatic alterations the ore-depositing solutions were characterized by their richness in fluorine, aluminum, silicon, calcium, tin, tungsten, iron, manganese, arsenic, sulphur, lithium, potassium, and sodium, but contained also copper, lead, and zinc, and locally boron in abundance. The state of combination of the various elements in solution is not known. The vein material includes various silicates, such as topaz, zinnwaldite, tourmaline, and albite, and proves that conditions unusual in the formation of the ordinary types of veins prevailed. Albite and tourmaline are commonly regarded as indicative of the magmatic derivation of vein-forming waters, and topaz and zinnwaldite are the two most characteristic of the so-called pneumatolytic minerals. The presence of topaz in the vein matter itself is somewhat unusual, inasmuch as this mineral, although common in the greisen adjoining quartz-cassiterite veinlets in granite as a replacement of feldspar, is comparatively rare as a fissure filling. Of the minerals contained in the veinlets as Cassiterite Creek all, with the notable exception of quartz, have also developed metasomatically in the limestone. It is noteworthy that cassiterite, though present in large proportions in many of the veinlets, appears only in insignificant amounts in the intensely altered wall rock. In addition hornblende, vesuvianite, garnet, and others were formed, and prove that conditions allied to those obtaining during contact metamorphism prevailed. The stanniferous solutions were therefore presumably of magmatic origin and at high temperature and pressure.

The abundance of fluorine compounds—fluorite, topaz, and zinnwaldite—is in harmony with Daubrée's generalization[a] that fluorine is the active agent in the formation of tin deposits. According to

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[a] Daubrée, A., Géologie expérimentale, p. 38.

his theory cassiterite is produced by the mutual decomposition of the vapors of water and stannic chloride reacting as follows:

$$SnCl_4+2H_2O=SnO_2+4HCl.$$

He was actually able to synthesize cassiterite in this way.

According to analogy we would expect—

$$SnF_4+2H_2O=SnO_2+4HF.$$

Cassiterite has been produced at red heat by Deville and Caron [a] in conformity to this equation. Quartz can be synthesized according to an analogous reaction. In recent years Vogt [b] has been a vigorous exponent of the pneumatolytic or gas-aqueous origin of cassiterite deposits. He conceives that hydrochloric and hydrofluoric acids acting on a cooling granite magma effect an acid extraction of tin and the various elements associated with it. Gaseous conditions are therefore considered as dominant during the formation of cassiterite bodies, and the final individualization of the minerals is held to be due to the reactions of Daubrée's experiments.

Certain facts in the Lost River area suggest that fluorine is not, however, absolutely essential to the formation of cassiterite. On the Dolcoath dike some of the richest ore is intergrown with danburite ($CaB_2(SiO_4)_2$) and the limestone shows no fluorite, although the latter is common in the vicinity of the Cassiterite lode. Moreover, the cassiterite includes multitudes of tourmaline microlites, so that there is obviously a closer association of the tin with boron than with fluorine. On the other hand, the wolframite-topaz lode, with its content of galena and stannite, proves that tin and abundant fluorine may coexist in the same solution and cassiterite not be formed.

PLACERS.

BUCK CREEK.

Developments subsequent to 1905 have revealed few new facts of interest in regard to the placers of Buck Creek. The gravels have a length of about 4 miles and are shallow. Work below the mouth of Sutter Creek has shown that the gravel in that part of the stream is from 120 to 160 feet wide, averaging about 125 feet. The width of the pay streak is not known. A pit having a mean depth of 5 feet, from which 48 tons of concentrates have been extracted, has demonstrated that the gravel may run as high as 25 pounds per cubic yard. The gravel is a comparatively fine wash and bowlders are rare, the

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[a] Compt. Rend., vol. 46, 1858, p. 764.

[b] Zeitschr. prakt. Geologie, 1895, p. 475.

largest noted consisting of greenstone about a foot in diameter. The richest gravel rests immediately upon bed rock and is exceedingly clayey and toughly bound together. It gives difficulty in washing, the clay having a tendency to roll up in balls and carry cassiterite nuggets over the sluice boxes. The bed rock is a broken shale or slate, very clayey, but contains no cassiterite. On Sutter Creek, the large southern branch of Buck Creek, there is a considerable body of gravel, and the discovery of stream tin has recently been reported on it. The other tributaries, gulches, and "benches" of Buck Creek contain little or no gravel, at least in amounts sufficient to warrant an outlay for the purpose of placer mining.

The stream tin of Buck Creek is clearly derived from the erosion and concentration of the cassiterite occurring in the quartz stringers so abundant throughout the area. This source was partly supplemented by the cassiterite occurring in the actinolite rock, and to a lesser extent by that contained in the quartz porphyry dikes. As these bed-rock sources are known to occur in place on the summit of the hills at the head of Buck Creek, it is probable that some of the creeks flowing into Lopp Lagoon carry stream tin. But whether cassiterite is present in these streams in payable quantities is purely a matter of accurate sampling, and not of opinion or theory—an idea which prevails in certain quarters to the detriment of the region.

Two companies were in operation on Buck Creek during 1907, but on account of a number of adverse circumstances the yield was less than was expected. Placer mining was confined to a small strip just below the mouth of Sutter Creek, and the total output of the year was approximately 50 tons of concentrates.

At the beginning of the season the American Tin Mining Company was working its ground by means of an automatic scraper and belt conveyor operated by a 35-horsepower oil-burning engine. Early in August, however, extortionate freight rates on the transportation of crude oil from Nome to York and the imperfect adaptation of the scraper to the character of the gravel necessitated a change in the method of working. Shoveling in was then adopted, with results at least more satisfactory than those attained with machinery. The other company also employed the shoveling-in method, and the tailings were removed by a horse and scraper.

GROUSE CREEK.

During the summer of 1907 assessment work was done on a number of claims on Grouse Creek and two of its tributaries, Sterling and Skookum creeks. The results are not known. Some gold sifted out of the stream-tin concentrates from Sterling Creek was flat, coarse, and not greatly waterworn, and had quartz still adhering to it.

FAIRHAVEN DISTRICT.

A sample of black-sand concentrates from Humboldt Creek sent in to the office for determination proved to be a rich tin ore containing less than $5 per ton in gold. About two-thirds of the sample was pyrite. Another sample of concentrates sent in from Kougarok River was found to contain considerable cassiterite, but far less than the Humboldt Creek sample. It carried, however, 85 ounces of gold per ton and contained 66 per cent of pyrite and about 10 per cent of magnetite. As the headwaters of Humboldt Creek drain the Hot Springs granite area, the tin was probably derived from that region. Collier states that samples of tin ore purporting to come from it were brought to Nome late in the season of 1902.

RÉSUMÉ AND CONCLUSIONS.

Four localities in the western part of Seward Peninsula are being prospected for lode tin at the present time. From one stream—Buck Creek—placer tin is actually being extracted, and an output of approximately 50 tons of concentrates was attained in 1907.

The sedimentary rocks of the York region comprise a series of slates of unknown but probably early Paleozoic age, a thick volume of thin-bedded limestone of Ordovician age (Port Clarence limestone), and crystalline limestone of Carboniferous age. At Ear Mountain contorted limestones and lime-mica schists prevail. These rocks are intruded by a number of granite masses, which, though appearing in isolated stocks, show by the many features that they possess in common that they belong to the same irruptive magma. The granites are coarse-grained types with large porphyritic feldspars and quartz which is commonly of a conspicuously smoky character. They were unusually rich in volatile constituents, among which boron, fluorine together with chlorine, and iron were the most prevalent, and they are therefore characteristically surrounded by pneumatolytic contact aureoles. Large amounts of the magmatic emanations were retained by the limestones in such minerals as tourmaline, axinite, ludwigite, hulsite, paigeite, boron vesuvianite, magnetite, hedenbergite, fluorite, scapolite, and chondrodite.

Complementary contact phenomena occur at Cape Mountain, where giant granite selvages are overlain by fluoritic and scapolitic pyroxene hornfels containing accessory scheelite. These phenomena are regarded as showing on the one hand the effect of the mineralizers on the crystallization of the magma, and on the other hand their effect in producing intense metasomatic action on the adjoining limestone. Essentially similar metasomatism was produced by a pegmatite intrusive in the marble surrounding the granite stock of Brooks Mountain. Along Tin Creek a novel type of contact metamorphism which has produced perfect orbicular forms has occurred. The orbules are allied in their origin to garnet-vesuvianite masses, which have injected small banded apophyses, as it were, into the inclosing limestone. The supply ducts for the orbules consist of curious banded veins composed of fluorite, calcic plagioclase, and pyroxene, with accessory arsenopyrite, cassiterite, and scheelite.

The tin deposits are genetically associated with the granitic intrusives. Cassiterite occurs in a variety of ways:

(1) In a tourmaline-axinite hornfels.

(2) In beds of actinolite rock which are probably interstratified with slates.

(3) In tourmalinized margins of granite masses and granitic dikes.

(4) In mineralized quartz porphyry dikes.

(5) In quartz veins cutting granite and accompanied by impregnation of the adjoining granite.

(6) In quartz stringers cutting slates and limestones.

In addition, tin is found to be present as paigeite (an iron-tin borate) in lime-silicate hornfels.

At Ear Mountain cassiterite occurs in a contact-metamorphosed limestone consisting essentially of tourmaline, axinite, and actinolite, but it is not found in any of the other pneumatolytic contact rocks of the region. This is a fact of considerable interest from the standpoint of ore genesis. The stanniferous granite magma was rich in halogens and boron, and theoretically the limestones are favorable loci for the precipitation of cassiterite. By the action of stannic chloride ($SnCl_4$) vapor on lime Daubrée[a] was able to synthesize cassiterite. The limestone contacts might therefore be expected to show this mineral. But as a matter of fact the contact rocks, although rich in pneumatolytic minerals, are as a rule barren of tin. The advent of the cassiterite was postponed to a later stage, and where evidence can be obtained as to the relative ages of intrusion and mineralization the latter postdates the injection of the quartz porphyry or rhyolitic dikes. This would appear to indicate that a long period of preliminary concentration was taking place in the cooling magma.

The rarity of cassiterite as a contact-metamorphic mineral the world over is anomalous. As far as the writer is aware the only deposit in which it is unequivocally of contact-metamorphic origin is that in the Dartmoor Forest, Devonshire, England, described by Busz.[b] At this locality hornfels adjoining the granite contact consists essentially of light-colored mica, quartz, and tourmaline with innumerable grains and minute crystals of cassiterite scattered throughout the rock.

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[a] Compt. Rend., vol. 39, 1854, p. 138.

[b] Busz, K., Neues Jahrb., Beil. Band 13, 1899, p. 100.

At the St. Dizier mine,[a] in Tasmania, cassiterite occurs in a magnetite-silicate rock of the Kristiania type, but it is not entirely clear whether the cassiterite is contemporaneous with the other constituents. According to Twelvetrees[b] the tin-bearing rock at the Stony Ford mine, Tasmania, is a band of quartz-chlorite rock, charged with pink garnets, pyrite, some blende and chalcopyrite, and cassiterite. This is regarded as probably resulting from the contact metamorphism of slates and sandstone. At Pitkaranta, Finland, cassiterite occurs lining druses along a definite formation consisting of lime-silicate rock ("skarn") that was produced in early pre-Cambrian time by the contact metamorphism of a limestone. The tin ore, however, is connected with the intrusion of the Rapikiwi granite of late pre-Cambrian age, and is regarded as of contact-metamorphic origin, being due to magmatic solutions flowing along pervious contacts. This conception[c] of the genesis of the deposits would practically extend the term contact metamorphism to all deposits formed by juvenile waters of high temperature.

A remarkable similarity, both mineralogic and geologic, exists between these deposits and those of Schwarzenberg in Saxony,[d] where cassiterite occurs as a secondary impregnation in a salite-tremolite rock which at some distance from the contact encircles a granite mass. Dalmer, however, would include these deposits as a phase of contact metamorphism, using that term in its largest sense. From this review it would appear that stanniferous contact deposits of the Kristiania type are of extremely rare occurrence. One such deposit of commercial importance has yet to be found. This is certainly a surprising fact in view of the commonly accepted theory of the pneumatolytic origin of the majority of tin-ore deposits.

The Alaskan tin deposits exhibit a number of unique features. These include the association of cassiterite and arsenopyrite in a gangue of actinolite; the intergrowth of cassiterite with the rare calcium borosilicate, danburite; and the occurrence of an argentiferous wolframite-topaz lode containing galena and stannite. An opportunity has been afforded by the prevalence of limestones in the region to study the metasomatism connected with cassiterite veins in such rocks, and the study has shown that it resembles contact metamorphism in its dual aspect—that is, metamorphism both with and without addition of material.

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[a] Waller, G. A., Tin-ore deposits of Mount Heemskirk, Govt. Geol. Office, Tasmania, 1902, p. 46.

[b] Twelvetrees, W. H., Tin mines of the Blue Tier, Govt. Geol. Office, Tasmania, 1901, p. 29.

[c] Trüstedt, O., Die Erzlagerstätten von Pitkäranta am Ladoga-See: Bull. Comm. Geol. de Finlande, No. 19, 1907. p. 316.

[d] Beck, R., Erzlagerstätten, 2d ed., Berlin, 1903, p. 444.

In general, the tin shows the intimate association with fluorine and boron observed in most tin deposits the world over, an association that is emphasized by the discovery of the new iron-tin borates as essential constituents of lime-silicate contact rocks in the metamorphic aureoles of granitic intrusives.

PRACTICAL DEDUCTIONS.

Developments in this region have been sufficient to demonstrate, at least, that the granite-limestone contacts are not favorable places to hunt for commercial bodies of cassiterite ore. Although a great variety of contact-metamorphic rocks have been produced around the peripheries of the granites only a few that are stanniferous were found, and in only one was even a small amount of cassiterite detected. The bunchy and erratic character of contact-metamorphic ore bodies has been repeatedly emphasized in the preceding pages, and attention has been drawn to the difficulty of mining such deposits occurring along irregular contact surfaces. The same drawbacks pertain also to tin ore found in the tourmalinized borders of the granite stocks. In view of the widespread belief in Seward Peninsula that contact deposits are likely sources of tin ore, it is worth while to review here what is known of cassiterite contact-metamorphic deposits in other parts of the world. There has been an actual production of tin from two only—Pitkaranta in Finland and Schwarzenberg in Saxony—and in amounts that are relatively small. The ore at these localities contains pyroxene and other minerals common in the Alaskan contact-metamorphic deposits, but the ore formation is confined to certain definite strata that were evidently favorable to the precipitation of the cassiterite. Some tin ore deposits of probable contact-metamorphic origin have been reported from the Stony Ford mine[a] and St. Dizier mine[b] in Tasmania, but they have not entered the ranks of large producers.

Quartz porphyry dikes, locally known as lodes, or even as quartz veins, have been prospected to some extent, owing to the fact that the original discovery of lode tin in Alaska was made on a mineralized and altered dike of this character. The value of any such dike depends on the number of cassiterite stringers which it contains and the closeness with which they are spaced. Of itself, a quartz porphyry dike has no value. The unwelcome fact should be speedily realized that few of these dikes hold out any inducements whatever as prospective tin producers.

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[a] Twelvetrees, W. H., Tin mines of the Blue Tier, Govt. Geol. Office, Tasmania, 1901, p. 29.

[b] Waller, G. A., Tin ore deposits of Mount Heemskirk, Govt. Geol. Office, Tasmania, 1902, p. 46.

Most of the developments throughout the region are still in the prospecting stage, and many of the open cuts have not uncovered solid bed rock. No tonnage of tin-bearing rock, except at one place on Lost River, has yet been blocked out. Small holes in the ground, which give no clew to either dip, strike, or persistence of the ore rock, are held at enormous figures. The great need of the country is less desultory prospecting. The slate area deserves more careful examination, as it is possible that valuable quartz veins may exist within its confines. The distribution of stream tin in Anikovik River and its tributaries proves that the stanniferous mineralization is not limited to the region at the head of Buck Creek, but is more widely spread throughout the slate belt.

It is probable that a great granite mass, of which the stocks at Brooks Mountain, Tin Creek, and Cape Mountain are protruding bosses, underlies the entire York region. As shown by the prospects of tin, tungsten, copper, lead, and zinc, and probably gold, this magma was capable of effecting a varied mineralization. As the region becomes better known and more thoroughly prospected, additional discoveries will probably be made from time to time.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 359

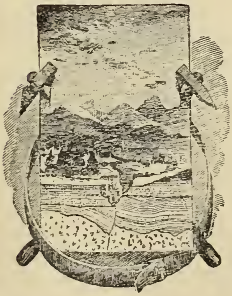
MAGNETITE DEPOSITS OF THE CORNWALL TYPE

IN

PENNSYLVANIA

BY

ARTHUR C. SPENCER



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MAGNETITE DEPOSITS OF THE CORNWALL TYPE IN PENNSYLVANIA.

By Arthur C. Spencer.

INTRODUCTION.

The deposits of iron ore which form the subject of the present report occur near the edges of the belt of Mesozoic rocks which enters Pennsylvania along Delaware River above Trenton, N. J., and extends across the State in a general southwesterly direction to the Maryland line. Though the deposits have been described by several geologists the present study was undertaken in the belief that an investigation of somewhat broader scope than any of those previously attempted might lead to an understanding of the manner in which the ores were formed, and that a knowledge of their genesis might warrant practical suggestions looking to the discovery of ore bodies as yet unknown. The work has been somewhat disappointing, because the observed facts do not establish a complete theory regarding the origin of the ores, but from a practical standpoint the results are thought to be of value.

The older descriptions deal mainly with those relations of the ore bodies exhibited in the mines or pits from which ore was being extracted, but the deposits are here considered in the light of their geologic setting. The writer has used much of the information recorded by earlier geologists and has quoted some of their statements, to which many of his own observations are merely supplementary. The field work was done during the autumn of 1906 and the summer of 1907.

GEOLOGY OF EASTERN PENNSYLVANIA.

GENERAL STATEMENT.

The rocks of Pennsylvania, as recognized by the first State geologist, H. D. Rogers, fall naturally into three main divisions—the pre-Cambrian gneisses, schists, and volcanic rocks; the Paleozoic stratified formations; and the Mesozoic stratified formations with associated igneous rocks. All these divisions are represented in the southeastern portion of the State, in the region covered by Franklin, Adams, York, Chester, Lancaster, Dauphin, Lebanon, Berks, Montgomery, Delaware, Philadelphia, Bucks, and Lehigh counties, though the pre-Cambrian and Mesozoic rocks are confined to the region which lies southeast of the Allegheny Mountain front and to the limestone valley which trends from southwest to northeast through Cumberland, Dauphin, Lebanon, Berks, and Lehigh counties.

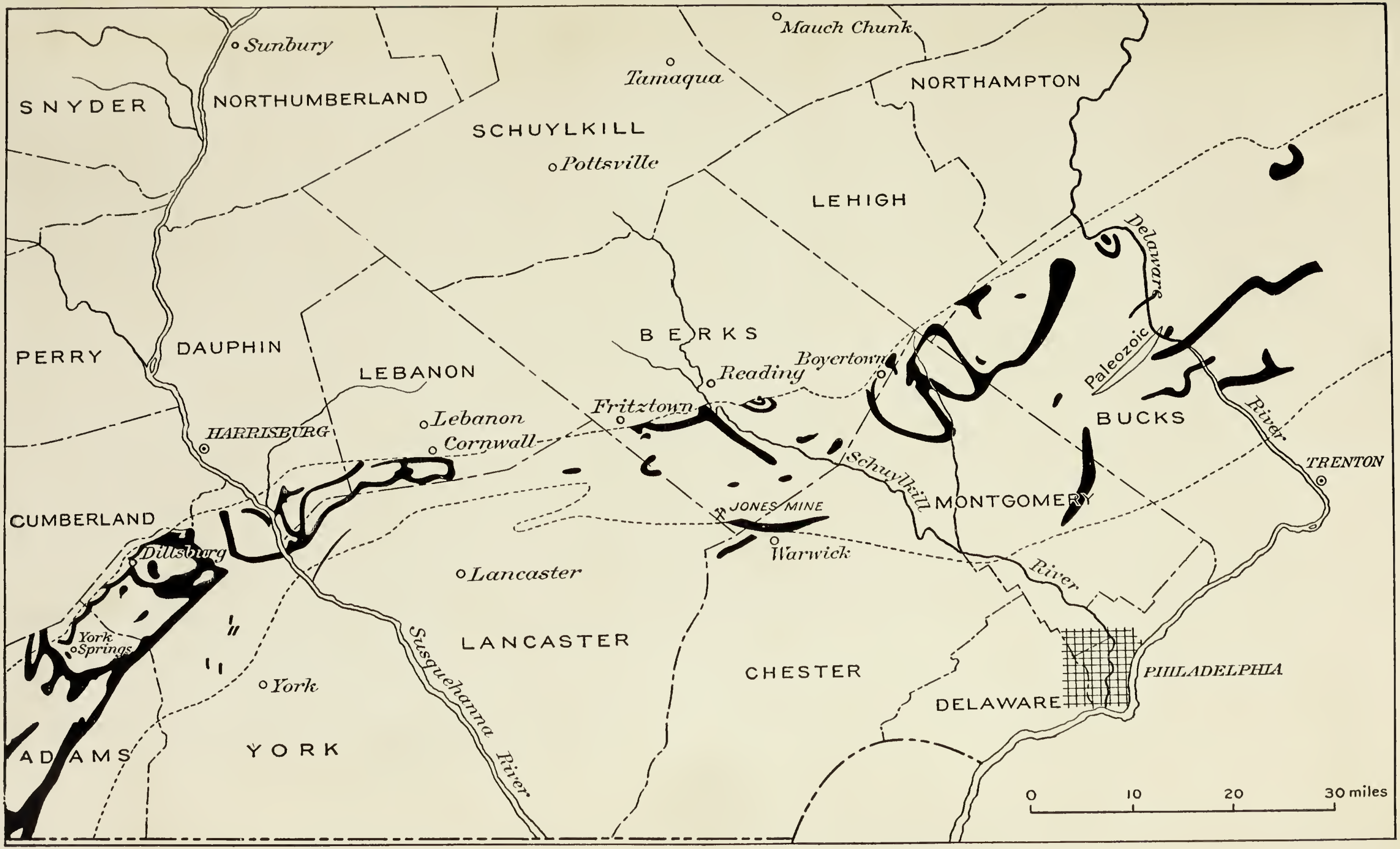
By folding and faulting the original surface between the ancient crystalline rocks and the lowest Paleozoic beds has been complexly contorted and broken, so that great masses of the Paleozoic formations are downset into the basement rocks. In four districts deep erosion of relatively upthrown blocks has revealed the pre-Cambrian formation. In Franklin and Adams counties the pre-Cambrian rocks of South Mountain are largely of volcanic origin. They are here intricately infolded with Paleozoic quartzites and limestone. In the vicinity of Philadelphia and southwestward from that city the pre-Cambrian rocks include schists and massive igneous intrusions. In northern Chester County and in Berks and Lehigh counties they are mainly granular gneisses.

SEDIMENTARY ROCKS.

Of the many formations which are comprised in the whole of the Pennsylvania Paleozoic section only the Cambrian quartzites, the Cambro-Ordovician limestones, and the Ordovician shales occur in the region here under discussion. In the following pages these divisions of the Paleozoic sequence are designated as "No. I" sandstone, "No. II" limestone, and "No. III" shale, in accordance with the usage of the Second Geological Survey of Pennsylvania. Taken together, formations "I" to "III" extend over a belt of country from 10 to 20 miles wide, lying southeast of the Allegheny Front. The limestone, being relatively much thicker than the sandstone, is the more prominent of the two, while, as the uppermost of the three members, the shale has been more extensively removed by erosion than the limestone and sandstone.

The Mesozoic strata, made up principally of coarse-grained red sandstone and red shale, are distributed in a belt from 8 to 12 miles wide, extending from Delaware River in a southwesterly direction to the Schuylkill, thence westward to the Susquehanna, and from the Susquehanna again southwestward to the boundary between Pennsylvania and Maryland. Locally, heavy beds of limestone conglomerate are present.

Though these red formations are now commonly designated the Newark group, they are here called simply Mesozoic, the term being



MAP OF THE MESOZOIC BELT IN PENNSYLVANIA, SHOWING PRINCIPAL INTRUSIONS OF DIABASE.

Data in part from Second Geological Survey of Pennsylvania.

consistent with Paleozoic, which it has been found convenient to employ in the descriptions that follow. Considered in reference to other stratified Mesozoic formations which overlap the Newark rocks in eastern New Jersey, the latter are properly designated as lower Mesozoic, but failure thus to particularize their position in the stratigraphic column leads to no confusion in discussing the geology of Pennsylvania.

The belt of Mesozoic rocks in eastern Pennsylvania is part of an unbroken curving zone about 300 miles in length, extending from the west shore of Hudson River across New Jersey, Pennsylvania, and Maryland, and into Virginia as far as Culpeper County. Several outliers in the continuation of the general course of this belt are found in southern Virginia and in North Carolina, while northward from Hudson River there is an extensive basin of corresponding rocks in the valley of Connecticut River, and another bordering the southeast side of the Bay of Fundy in Nova Scotia.

In Pennsylvania the Mesozoic strata were deposited upon a previously eroded surface on which were exposed all the older rocks now represented in the region. In places along the borders of the Mesozoic belt pre-Cambrian gneisses are present. Elsewhere "No. I" sandstone or "No. III" shale is overlapped by the Mesozoic strata, but on the whole "No. II" limestone forms the usual basement. Bowlders entering into the make-up of the limestone conglomerates that occur in places along the edge of the belt have evidently been derived from the formation last mentioned.

IGNEOUS ROCKS.

The zone comprising the various Mesozoic basins is characterized by intrusions of diabase or surface flows of basalt, both of which are commonly called trap rock, or simply trap (Pl. I). The diabase dikes occur in the districts between the several basins, and southward along the general trend of the zone they persist across South Carolina and well into Alabama. Although the strip of country in which the dikes are present is considerably wider than any of the separate belts of Mesozoic strata, the great bulk of the igneous material is associated with the Mesozoic rocks. In New England and New Jersey both extensive surface flows and invading masses are present, but in Pennsylvania nearly all of the igneous rock is distinctly intrusive. The intrusions are mainly sills which follow the bedding of the invaded formations more or less closely, but local and even extensive cross-cutting may be observed.

As the igneous material could not have originated either within the mass of the Mesozoic sediments or within the underlying Paleozoic formations, a deep-seated source must be admitted. In order to have reached the positions which it now occupies the diabase must have come up through channels traversing the lower Mesozoic strata and the basement rocks beneath them. Presumably the ordinarily narrow dikes that occur outside of the Mesozoic belt were feeders for intrusive sills and for surface flows associated with portions of the Mesozoic sediments which have been removed by erosion. If this be true the feeders of the sills that still remain are perhaps for the most part similar narrow dikes.

The ore deposits described in the following pages are intimately associated with intrusive masses of diabase and most of them are contained in calcareous strata, either in the limy rocks belonging to Paleozoic " No. II " limestone, outcropping near the edge of the Mesozoic belt, or in the beds of limestone conglomerate that locally mark the base of the Mesozoic section. Since the deposits are situated in each case near the surface of unconformity between the Mesozoic and the underlying Paleozoic formations, there is reason to believe that the diabase masses associated with the ores are bodies which cut across the Paleozoic basement rocks. These masses are of considerable size. Some of them were evidently the feeders of sills which penetrate the Mesozoic strata.

GENERAL DESCRIPTION OF ORE DEPOSITS.

The Cornwall type of iron ore is so called from the important Cornwall mine in Lebanon County, Pa. The ores are essentially magnetite, but they contain pyrite in amounts which make it necessary to roast them before they can be used in the blast furnace. Some specular hematite occurs in certain of the mines, but the amount of this mineral is relatively unimportant.

The ore occurs in large and small masses of varying form, either entirely inclosed by stratified sedimentary rocks or lying in such rocks where they come in contact with masses of intrusive diabase. The ore minerals appear to have been formed by more or less complete chemical substitution in the body of the rock, the portion of the rock not replaced constituting the principal gangue of the ore. Aside from the deposition of the iron minerals the limy strata associated with the ore bodies show remarkably little metamorphism, and though a few characteristic minerals of contact metamorphism occur they are so uncommon as to almost escape observation. The Cornwall mines have yielded more than 20,000,000 tons of ore, from what is essentially a single great ore body, though it contains extensive partings of barren rock. The other deposits are all much smaller, though several of them are still of important size.

COMPOSITION OF THE ORES.

The iron content of these ores is extremely variable, but as the ore is mined probably averages not far from 45 per cent. Rather constant chemical characteristics are low phosphorus, high sulphur, silica, lime, and magnesia, and the presence of copper. Small amounts of cobalt have been found in ores from Cornwall and Dillsburg. Many analyses of ore from the different mines may be found in the reports of the Pennsylvania Geological Survey, from which the following are extracted:

Partial analyses of Cornwall ore.

[A. S. McCreath, analyst.]

	1.	2.	3.	4.
Metallic iron	64.900	51.450	48.800	41.900
Metallic manganese	.158	.072	.057	.194
Metallic copper	.005	.559	.599	.319
Alumina	.324	1.080	2.315	4.970
Lime	1.010	2.600	4.330	2.810
Magnesia	1.131	6.652	5.531	7.457
Sulphur	.071	2.459	1.807	.428
Phosphorus	.014	.010	.018	.019
Silica	3.980	12.270	12.940	20.910
Phosphorus in 100 parts iron	.021	.019	0.036	.045

[a] Lesley, J. P., and D'Invilliers, E. V., Cornwall iron ore mines: Ann. Rept. Second Geol. Survey Pennsylvania for 1885, 1886, pp. 532, 533.

1. Analysis of 115 pieces of niggerhead ore from Middle Hill.
2. Analysis of fine or soft No. 3 ore from west cut, north side, Middle Hill.
3. Analysis of "No. 1 ore" from east face, Middle Hill.
4. Analysis of "No. 1 light ore" from west cut, south face, Middle Hill.

All the above were dried at 212 + ° F. before analysis.

Partial analyses of ores from Berks and York counties.[a]

	1.	2.	3.	4.	5.	6.
Iron	43.40	43.00	42.75	39.60	38.05	34.55
Silica	11.13	14.02	22.10	20.20	16.13	21.21
Alumina, lime, and magnesia	18.90	13.86	11.45	19.18	19.77	22.38
Copper	.01	.59	....	.12	.56	.17
Manganese	.01	....	....	.23	.42	.21
Sulphur	.43	.53	.59	1.94	1.14	1.64
Phosphorus	.09	.02	.01	.06	.04	.03

[a] Lesley, J. P., and D'Invilliers, E. V., op. cit., p. 537.

1. Black ore, 163 pieces, from Warwick mine, Boyertown, Berks County, A. S. McCreath.
2. Magnetic ore from Island mine, Reading, slope No. 1, Leonard Peckitt, Reading.
3. Dillsburg ore from A. Underwood's mine, A. S. McCreath.
4. Magnetic ore from Wheatfield mine, Berks County.
5. Magnetic ore, 25 pounds, from Island mine, Reading, A. S. McCreath.
6. "Blue ore," 20 pounds, from Phœnix mines, Boyertown, A. S. McCreath.

Workings at the surface formerly furnished soft ore free from sulphur, but this material gives place to hard sulphurous ore at relatively shallow depths.

DISTRIBUTION OF THE ORES.

So far as known, ores of the Cornwall type do not occur outside of Pennsylvania, though certain small veins of magnetite occurring in masses of intrusive diabase in Nova Scotia may be more or less closely related to them. In Pennsylvania the ores have been mined on a considerable scale at five localities in Berks County, namely: At Boyertown; at two places south of Reading; 7 miles southwest of Reading, near Fritztown; and near Joanna station, 2½ miles northeast of Morgantown. In Chester County they were formerly mined at Warwick, though this deposit is entirely exhausted. The great Cornwall mines are situated in Lebanon County, and near them are two other small deposits. In York County a large number of operations have been carried on in the vicinity of Dillsburg. Of all the deposits which have been mentioned only the one at Cornwall is now worked in a large way, though the several interests which formerly controlled the Boyertown properties have recently been consolidated so that these mines may be started at an early date. At Dillsburg some ore was mined in 1903, and surface mining on a small scale was in progress at the Wheatfield group in 1906; the other mines have been abandoned for many years.

GEOLOGIC RELATIONS OF THE ORES.

Though in the past there has been considerable discussion concerning the stratigraphic position of the deposits, it is now agreed that in York County they lie in Mesozoic strata and in most of the other localities in limestones or limy shales of Paleozoic age.[a]

The Cornwall deposit is situated at the top of "No. II" limestone of the Pennsylvania section, just under the "No. III" ("Hudson") shale; the Boyertown, Fritz Island, Raudenbusch, Wheatfield, and Jones deposits are in strata which apparently belong near the base of "No. II" limestone. The Warwick deposit lies at the base of Mesozoic beds that rest upon pre-Cambrian gneisses.

It has been found that large masses of intrusive diabase are present near each of the existing ore bodies and usually in actual contact with them. The existence of diabase near the mines is noted in every published description of these magnetite deposits, and the present investigation has served to emphasize both the size of these igneous masses and the importance of their relation to the ore deposits. It is thought, indeed, that the origin of the ores must have been directly connected with the intrusion of the igneous rocks.

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[a] Lesley, J. P., and D'Invilliers, E. V., op. cit. Also, D'Invilliers, E. V., Iron ore mines and limestone quarries of the Cumberland-Lebanon Valley: Ann. Rept. Second Geol. Survey Pennsylvania for 1886, pt. 4, 1887.

ORIGIN OF THE ORES.

REPLACEMENTS.

If the various deposits be considered together the theory of origin which seems to be required by their geologic relations is that the magnetite ore bodies of the Cornwall type have been formed by the more or less complete metasomatic replacement of sedimentary rocks by iron minerals precipitated from heated solutions set into circulation by the invading diabase. The rocks which have been thus replaced are usually limestones, limy shales, or limestone conglomerates.

Previous writers, including H. D. Rogers, T. Sterry Hunt, Persifor Frazer, jr., J. P. Lesley, and E. V. d'Invilliers, have held that while the present magnetic condition of the ores might be due to the metamorphosing effect of the trap rocks (diabase), the deposits had been formed before the introduction of these rocks.[a]

Material from almost any one of the mines affords abundant evidence that the ore minerals have been deposited by substitution or chemical replacement of the limy rocks. Much of the lean ore consists of alternating layers of the iron minerals and unaltered rock, showing definitely that certain portions of the rock have been more favorable for replacement than others. At Cornwall many examples may be seen in which thin layers of ore conforming to the stratification of the limy shales are connected by cross seams, which show beyond a doubt that the ore minerals could not have been formed contemporaneously with the inclosing rock, but that they must have been introduced subsequently. It is the writer's conception that the solutions which accomplished the deposition of the ores must have been in the condition of vapor when they penetrated the rocks.

SOURCE OF THE IRON.

The source of the solutions concerned in the formation of the ores and in the general metamorphism of the rocks in the vicinity of the igneous masses and the source of the iron which the deposits contain can not be satisfactorily determined. The observed facts lead to no definite conclusion on either of these points, though, all things con-

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[a] Rogers, H. D., Geology of Pennsylvania, vol. 2, 1858, pp. 687, 708, 718.

Hunt, T. S., The Cornwall iron mine and some related deposits in Pennsylvania: Trans. Am. Inst. Min. Eng., vol. 4, 1875, pp. 508–510.

Frazer, P., jr., Second Geol. Survey Pennsylvania, Rept. CC, 1877, pp. 198–400. Also, A study of the specular and magnetic iron ores of the new red sandstone in York County, Pa.: Trans. Am. Inst. Min. Eng., vol. 5, 1877, pp. 132–143.

Lesley, J. P., and D'Invilliers, E. V., Report on the Cornwall iron-ore mines, Lebanon County: Ann. Rept. Second Geol. Survey, Pennsylvania, for 1885, 1886, pp. 491–570; Final Rept. Second Geol. Survey Pennsylvania, vol. 1, 1892, pp. 351–357.

D'Invilliers, E. V., The Cornwall iron-ore mines, Lebanon County, Pa.: Trans. Am. Inst. Min. Eng., vol. 14, 1886, pp. 473–904.

sidered, if it be admitted that the heat of the intrusive rocks was the prime cause of the circulation of the solutions which formed the ore it appears more likely that both the waters and the iron were furnished by the igneous rock than that they could have been derived from an outside source. Possibilities which naturally present themselves are as follows:

1. The water was of meteoric origin and the iron came from the sedimentary rocks.
2. The water was of juvenile origin (that is, it was expelled from the igneous rocks) and the iron came from the sedimentary rocks.
3. The water was of juvenile origin and contained the iron in solution when it escaped from the igneous rocks.

The suggestion that ordinary ground waters could have been heated by the invading igneous rocks and thus have been enabled to cause extensive induration of the invaded Mesozoic strata, leaching them of their contained iron and concentrating it into ore deposits occupying the observed situation, is opposed by several considerations. In the first place, it appears that waters from any source outside of the igneous rock, whatever their natural courses of circulation, if unaffected by the intrusive masses, could never closely approach the heated bodies of rock, for the reason that steam would be generated in the vicinity of the contacts and the resulting pressure would tend to drive all waters outward from the source of heat. Under such conditions if ore deposits were formed they would not be segregated at the igneous contacts, but instead would be some distance away, which is contrary to the existing relations. A second argument against the suggestion is that the deposits are neither as numerous nor as widely distributed as would be expected if the iron had been contributed by the invaded formations. The only sedimentary rocks which can be considered as at all competent to have furnished sufficient iron for the known deposits are the Mesozoic sandstones and shales that occur in the vicinity of all the deposits, as the Paleozoic formations are made up of rocks containing very small amounts of iron. In so far as they have not been altered by the influence of the intrusive diabases the Mesozoic rocks are of almost uniform appearance throughout the region and from a few recorded analyses it may be judged that they carry from 5 to 8 per cent of iron oxide. Everywhere in the neighborhood of the intrusive masses the sandstone and shales have been extensively metamorphosed. In places balls of epidote have been formed in the shales; elsewhere small segregations of specular hematite occur in coarse sandstones; and in conglomerates some of the pebbles are surrounded by rims of garnet, tremolite, and hornblende. Changes of this sort characterize the more intense phases of metamorphism and are observed only near the diabase contacts; more extensive alteration of a less striking nature is manifested by a general induration of the rock and by a loss of the original red color.

Though the general bleached condition of the Mesozoic strata in the neighborhood of the intrusive masses points to these rocks as a possible source of the segregated iron, it is not certain that the whitened rocks have actually lost their iron, for the original amount of this element may still be present in a different chemical state. No investigation has been made to settle the question thus raised, but it does seem that if the iron of the sandstones has been depleted in a few places the same thing must have taken place generally, because the appearance of the altered rocks is the same in many places. If the known deposits of iron ore had been formed from solutions of this origin a certain amount of segregation should be found in association with the bleached rocks wherever they occur. The fact that the ore deposits are so localized is thus against the idea that the iron which they contain has been furnished by the sedimentary rocks.

The conclusion that the sedimentary rocks are not likely to have furnished the iron applies as well when the active waters are regarded as having come from the igneous rocks as it does when a meteoric source is assigned to them.

It can hardly be doubted that the general alteration of the shales and sandstones near the igneous rocks has resulted from the action of heated water and steam percolating through the sandstones and shales. If the waters which took part in the metamorphism had come out of the igneous rocks, either from the masses adjacent to the altered sediments or from much deeper masses which have not been exposed to view, they could hardly have made an excursion through the stratified rocks and later returned to the contact, as they must have done to have deposited the ore bodies at Boyertown, at Cornwall, at the Jones mine, and at the larger ore beds of the Dillsburg field.

Only one of the several adverse considerations presented above stands in the way of the suggestion that both the waters which effected the metamorphism and the iron which was deposited by these waters were driven from the igneous rocks; namely, the uncommonness of the deposits. If certain of the intrusive masses furnished iron for large deposits, why is it that similar segregations do not occur in association with every important mass of diabase? Though the question can not be satisfactorily answered, our general knowledge concerning the occurrence of ore deposits at igneous contacts points to the conclusion that the nature of the solutions given off by different parts of igneous rock masses is subject to wide variation, so that it is by no means necessary to believe that identical materials must have been introduced everywhere in the vicinity of intrusive masses of the diabase, even though the igneous rock be accepted as the source of the iron segregated locally at the contact with the invaded strata.

DIFFERENTIAL METAMORPHISM.

Whatever the actual source of the iron may have been, it can not be doubted that different masses of diabase within the same general field may have differed greatly in respect to efficiency in producing metamorphism, but, other things being equal, it can be assumed that the directness of the paths by which the intrusions came into their present positions must have been a very important factor influencing the relative amount of alteration and mineralization which the various masses of diabase were capable of producing. It seems evident that the transfer of heat and the movement of mineralizing waters must have continued for a much longer period in the vicinity of strongly crosscutting masses of igneous rock than adjacent to others having less direct connection with the deep-seated reservoir which supplied the molten rock material. This is accepted because the deep reservoir is conceived to have been the original source of all the energy involved in the chemical reactions of metamorphism and ore deposition.

PRACTICAL CONCLUSIONS.

The geologic features of the various deposits which have been studied are thought to warrant the following general suggestions to those who in the future may make practical explorations for new ore bodies in this field.

1. Ore bodies are to be sought only on or near the walls of masses of diabase.
2. Large masses of diabase are more favorable for ore deposits than smaller masses.
3. Crosscutting intrusions and highly inclined sills are more favorable than sills of low inclination.
4. Limestones and limy shales are far more likely to be replaced by ore than clay shales or sandstones.
5. Particularly favorable locations for ore are found in masses of limestone that lie between bodies of diabase and beds that are in a marked degree less susceptible than limestone to the metamorphosing influence of the igneous rocks.
6. The most promising situations will be found at places where the largest number of the above-stated favorable conditions occur in combination.

Many or all of the more favorable conditions enumerated existed at places where the larger ore deposits of the Cornwall type were formed, and as several of these conditions may be fairly inferred to exist in a few other localities, usually in the vicinity of the mines which have been operated, still other deposits of iron ore may yet be found in the same field. The geologic descriptions which follow have been prepared with especial reference to the possibility of indicating situations in which it may prove worth while to look for deposits of iron ore as yet unrecognized.

CORNWALL AND VICINITY.

CORNWALL DEPOSITS.

DISTRIBUTION AND SURFACE RELATIONS.

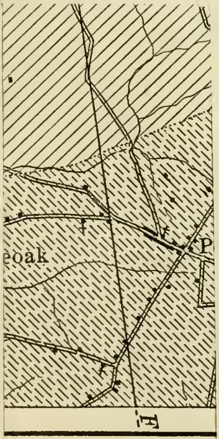
The Cornwall ore banks are situated 5 miles from Lebanon, Pa., on the south side of the Lebanon Valley, along the edge of which Paleozoic limestones and slates give place to intrusive diabase and to conglomerates, sandstones, and shales of Mesozoic age (Pl. II). The different formations have a general east-west trend through all this region, and for several miles both east and west of Cornwall the older (Paleozoic) and newer (Mesozoic) formations are separated by an intrusive mass of diabase which has a width in outcrop of 1,400 to 2,900 feet. The mines lie just south of this diabase in an isolated area of limestone, the southern boundary of which is formed by overlapping Mesozoic beds. Eastward from the ore hills for a distance of somewhat more than a mile a narrow strip of slaty rocks comes between the diabase and the lowermost Mesozoic strata exposed in this vicinity. West of the workings a narrower strip of the same rock in similar position outcrops for perhaps 1,000 feet. The limestones and interlayered limy shales south of the diabase have been more or less completely replaced by magnetite, somewhat contaminated by pyrite and chalcopyrite, and it is these impregnated strata that constitute the great deposit from which more than 21,000,000 tons of iron ore have been extracted since 1853.

The position and surface relations of the ore-bearing strata to the various rocks which have been spoken of in the foregoing paragraph are clearly exhibited on the maps (Pls. II and IV), and the cross-sections (Pl. III) indicate the supposed relations underground. These sections are intended to show the kind of structure that seems to be required by the existing surface distribution of the various kinds of rocks and by their strikes and dips, in so far as these can be observed. As guides the sections are believed to be of some value, but thicknesses, strikes, and dips of buried strata are manifestly not ascertainable factors in cases like the present, where masses of intrusive rock, and in addition a great unconformity of deposition, are involved in the structure to be interpreted.

On the surface the ore, together with such masses of lean or barren rock as accompany it, is bounded on the west, north, and east by diabase, a tongue of which likewise limits the Big Hill mine on the south. Between the tongue of diabase that forms the southern side of Big Hill and the first exposure of Mesozoic beds in the low ground immediately south of Miners village the slope is covered by loose débris, so that it is impossible to say what the distribution of the various rocks actually is. It seems very likely, however, that some of the strata which are elsewhere converted into ore occupy at least a portion of this hidden ground. South of the mines scattered outcrops serve to indicate rather closely the northerly limit of the Mesozoic rocks, the lowest bed of which is a conglomerate composed of angular quartz fragments in a cement of bluish clay. This peculiar rock has been called porphyry by casual observers, but its clastic nature is obvious on close examination. South of the present workings in Middle Hill, and for some distance toward the west, loose débris derived from the near-by hill covers the edge of the ore, but the blue conglomerate has been revealed in a reservoir excavation near the Mount Hope road, and this rock probably constitutes the immediate capping of the ore-bearing strata from this place eastward to the exposures along the railroad track just below the superintendent's office. West of the Mount Hope road the same rock may be followed for some distance, but in this direction its outcrop approaches the diabase, and the rock is considerably baked and indurated. On the little knoll just west of the road a narrow strip of slate is present next to the diabase, as previously mentioned.

The blue conglomerate appears to lie at the bottom of a series of carbonaceous shales which are partially exposed along the Mount Hope road, and are well exhibited 2 miles farther west in a cutting along the Cornwall and Lebanon Railroad. On the geologic maps (Pls. II and IV) the conglomerate and carbonaceous shales are represented by one pattern.

The area over which the ore-bearing strata were naturally exposed or have been revealed by stripping is roughly 4,000 feet long and from 400 to 800 feet wide, and its extent beneath a superficial covering of loose gravel and sandstone débris, though as yet not fully determined, would seem to be considerably more. From diamond-drill borings south of the present workings it is known that ore continues in this direction for at least several hundred feet beyond the edge of the Newark strata that cap the deposit, but the information afforded by these holes has not been available in the present study.



A.

GEOLOGIC SKETCH MAP OF VICINITY OF CORNWALL, LEBANON COUNTY, PA.

DIABASE INTRUSIONS.

The diabase next to the Cornwall deposit is an intrusive mass of considerable size and of complex shape. Along the north slope of the hills that face the Lebanon Valley its outcrop forms a continuous east-west band from a third to a half mile in width and 9 miles in length. This body is connected by two southward-trending arms with a second band, which lies about 2 miles farther south and extends with a west-southwest course across the Susquehanna into York County. This southern mass of diabase has the form of a sill which follows a group of carbonaceous shales showing generally northward dips. Shales of the same group may be traced along the edges of the connecting arms both east and west of the Cornwall mines, and though local crosscutting may be noted, it is evident from the field relations that these surface connections are merely portions of the extensive sill that have been uncovered by erosion. On the other hand, the diabase of the northern band is a crosscutting mass, for it is bounded on the extreme west by massive sandstones of the Mesozoic; then by the same rocks on the south and by Paleozoic limestones on the north; next, just south of Bismarck, by black Mesozoic shales on both sides; farther east by these shales and blue conglomerate on the south and by the slates which form Mill Ridge on the north; at the mines by the limestones impregnated with ore and the slates of Mill Ridge; east of the mines as far as Rexmont by these slates on both sides; and thence, to a point beyond the Lebanon waterworks main reservoir, by Paleozoic limestones on the north and by Mesozoic strata on the south, except where small outcrops of slate and limestone just south of the dike have been revealed by two of the three streams that supply the waterworks. (Through an error only two of these streams appear on the sketch map, Pl. II.)

From the conclusions that the southern diabase band is the cropping of a sill and that the northern band is a dike, it is but a natural step to regard the latter as having been the feeder of the former; and the warrantable belief that this is the actual relation forms the basis of the structure represented in the cross sections (Pl. III). That there is a connection between the dike and sill in the vicinity of the mines is indicated by the reported presence of diabase beneath the ore-bearing strata in all the diamond-drill holes that have been bored south and southwest of the present workings. It is hardly to be doubted that the sill forms a continuous sheet beneath the oblong area about 6 square miles in extent, which is surrounded by an unbroken outcrop of the diabase.

STRUCTURE OF THE BEDS.

Within this area, rimmed by diabase, the observed dips are toward the north, and the average inclination of the strata has been taken by Lesley and D'Invilliers[a] to be between 12° and 15°. If, however, the diabase mass be accepted as a sill following the group of carbonaceous beds, it is evident from the distribution of these shales that in that part of the area lying west of the Cornwall Railroad the effective dip toward the north must be much less than 12°, because the shales outcrop on the south side at elevations between 700 and 800 feet, and just south of the mines their croppings are barely 100 feet lower. East of the railroad the strata may be somewhat more steeply inclined, as higher and higher horizons of the Mesozoic strata come into contact either with the diabase dike or with the slates which adjoin it for nearly 2 miles eastward from Miners village. In this direction it seems that the carbonaceous shales are overlapped by higher beds of sandstone and red shales, so that their contact with the Paleozoic rocks may lie well back from the edge of the diabase dike and some distance below the lowest Mesozoic strata locally exposed by the stream cuttings.

In Lancaster County (Pls. II and III), beyond the southern edge of the sill, lower and lower Mesozoic strata emerge, with east-northeast strikes and constantly increasing northward dips, until the boundary with underlying slates is encountered about 2 miles south of Penryn. The basal contact on this side of the Mesozoic belt is a nearly straight line, trending slightly south of west, extending from Hopeland past Brickerville to the bend of Chickies Creek, just north of Whiteoak station, and thence nearly to Mastersonville, where it takes a more southerly course, reaching Susquehanna River at Bainbridge. Near this southern boundary the dips of the Mesozoic strata are steep and locally are even overturned. Allowing for the observed gradually decreasing inclination toward the north, we have an estimated thickness of strata amounting to about 6,500 feet between the bottom of the Mesozoic and the group of carbonaceous shales in which the intrusive sill occurs; yet near the Cornwall mines, barely 1½ miles north of the point where the shales outcrop, and south of Bismarck, about 2 miles distant, the same beds are seen to have been deposited directly upon the Paleozoic rocks. This striking relation and its proper interpretation have an evident bearing on the correct understanding of the structural features of the Cornwall deposit, and consequently on any attempt to determine the possibility of the existence of other similar deposits in the neighborhood. The explanation suggested is that the Mesozoic beds were laid down under such circumstances that successively higher strata were spread

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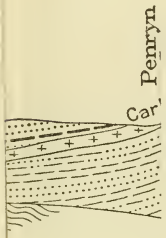
[a] Cornwall iron-ore mines: Ann. Rept. Geol. Survey Pennsylvania for 1885, 1886.



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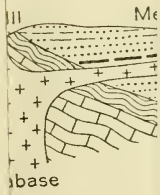

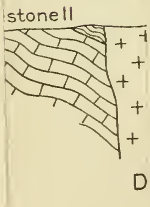

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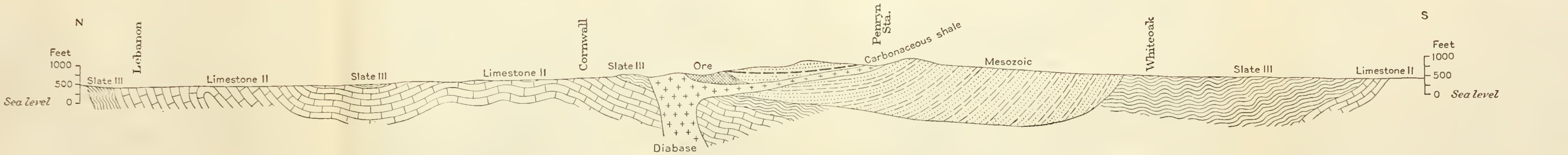
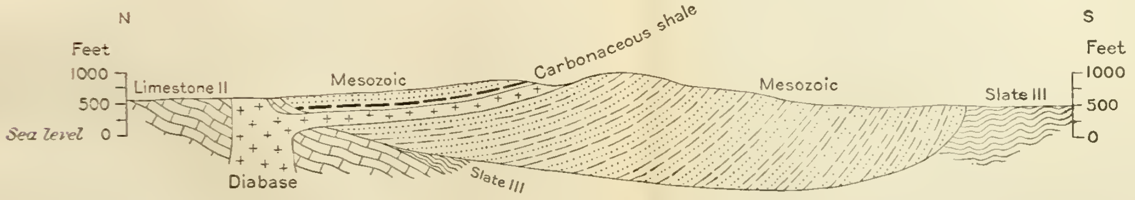


SECTION ALONG LINE A-B, PL. II



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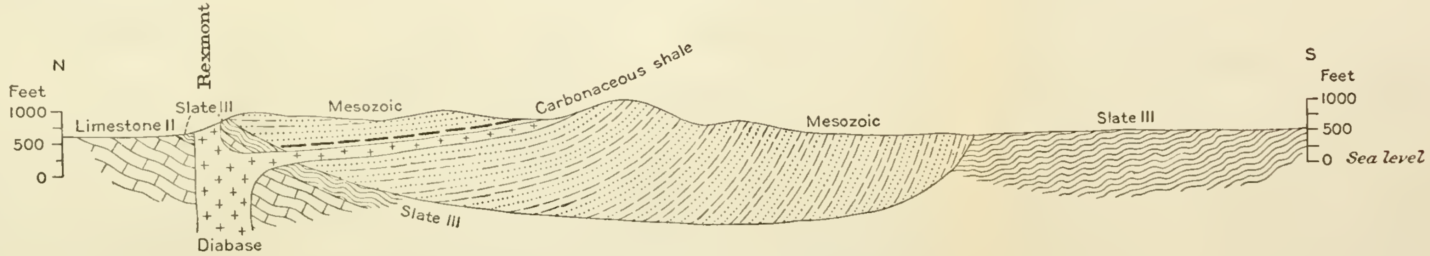
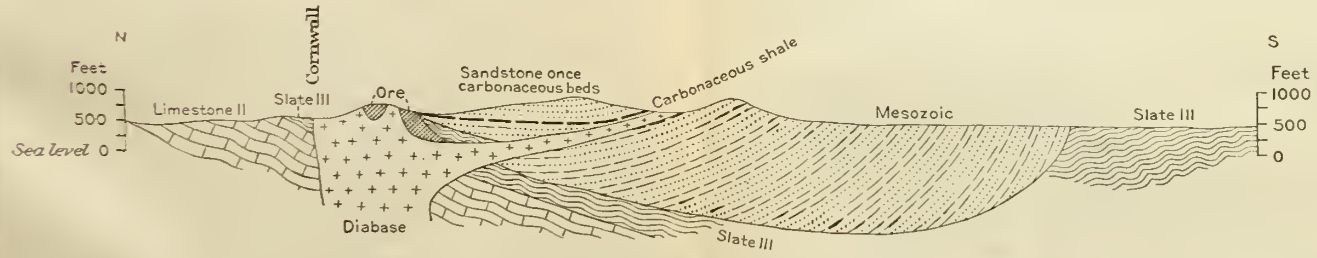
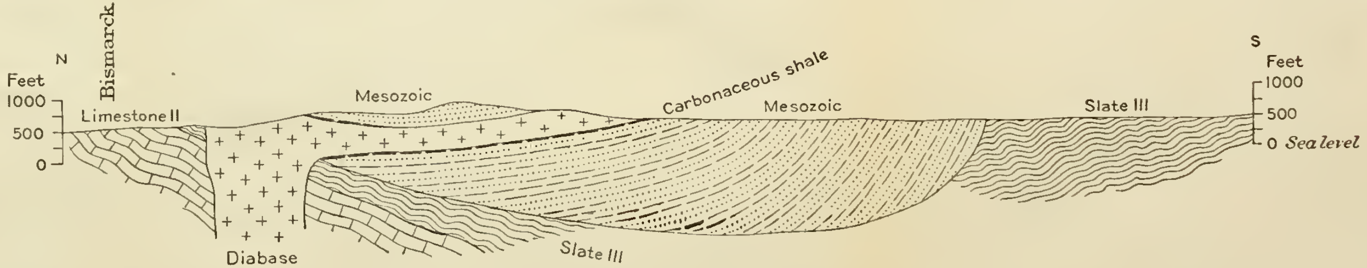


SECTION ALONG LINE E-F, PL. II



SECTION ALONG LINE G-H, PL. II



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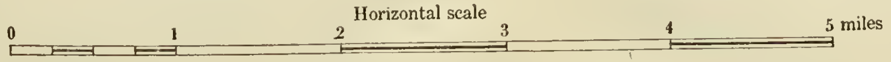
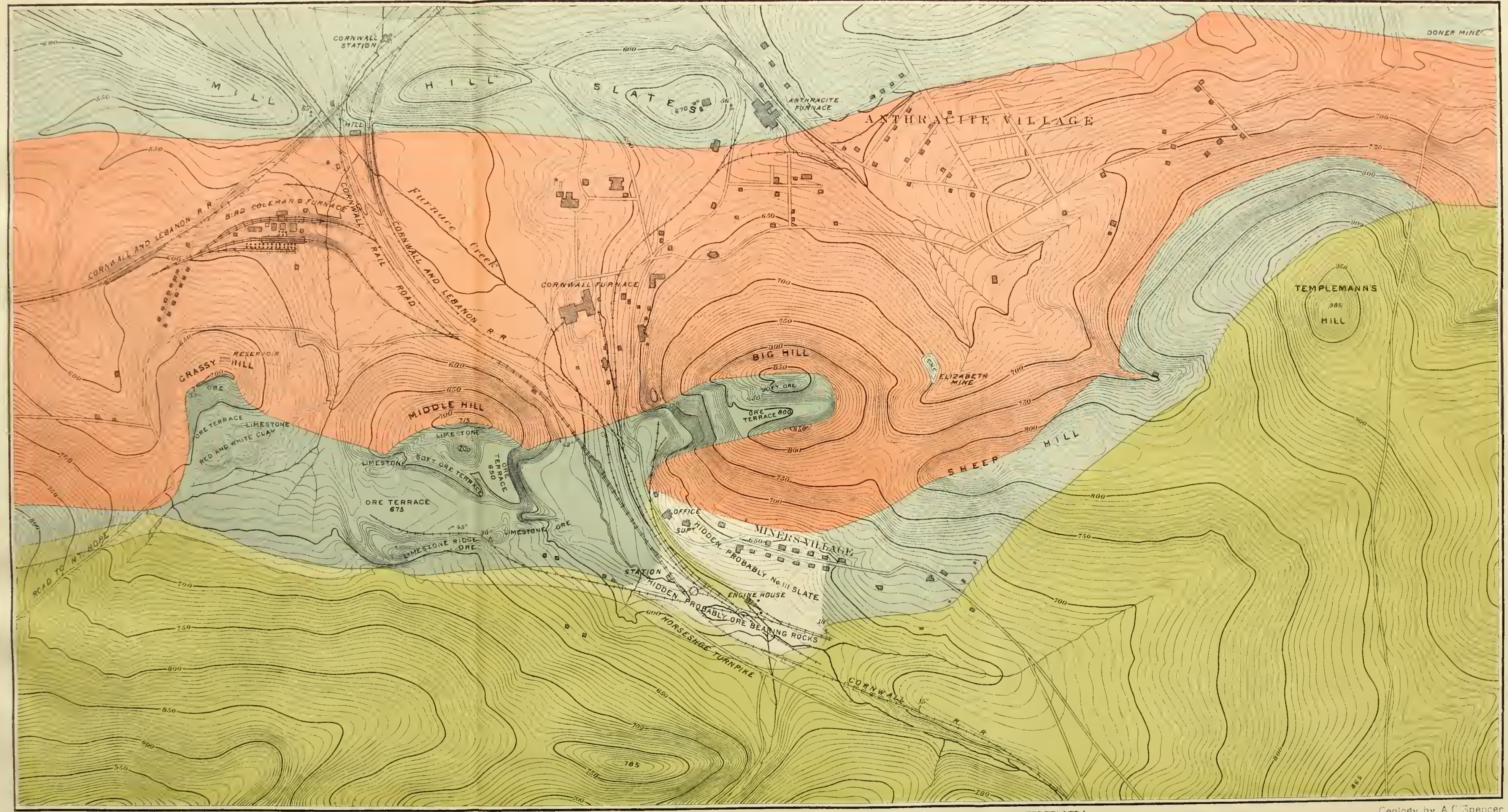


STRUCTURE SECTIONS IN VICINITY OF CORNWALL, LEBANON COUNTY, PA.

PENNSYLVAN



LEGEND

🟩 Mesozoic conglomerates sandstones, and shales

🟨 Blue conglomerate bed at base of Mesozoic

▨ Paleozoic No. II limestone and limy shale, the latter partly converted into ore

⬜ Paleozoic No. III slate ("Mill Hill" slate of Lesley and D'Invilliers

🟧 Intrusive diabase

Base from Geological Survey of Pennsylvania Annual Report 1885

A. B. GRAHAM CO. WASH. D. C.

GEOLOGIC MAP OF CORNWALL MINES AND VICINITY, LEBANON COUNTY, PENNSYLVANIA

500 0 500 1000 1500 2000 feet

Contour interval 5 feet

Datum is mean sea level

1908

Geology by A. C. Spencer

farther and farther toward the north against a continually receding shore. In other words, the facts observed indicate that the Mesozoic basin was sinking and widening as deposition went on, so that from south to north there is a marked overlap of the Mesozoic strata upon the Paleozoic basement. On the assumption that to this overlap is due the disappearance of the lower strata toward the north, a structure section from Lebanon to Whiteoak station has been drawn to show the general relations of the rocks (Pl. III). The north end of the section as far as Mill Ridge has been copied from the report of Lesley and D'Invilliers.[a] It is to be observed that inasmuch as nothing is known concerning the width of the dike below ground or the attitude of its walls in depth the representation of these features on the section is entirely conjectural; also that in showing the Paleozoic limestone and slate beneath the Mesozoic rocks the intention is merely to suggest that they form a basement upon which the younger strata were deposited, and not to present even a guess concerning the structure or distribution of these formations underground.

EXTENT OF THE DEPOSITS.

General statement.—Attention may now be directed to the manner in which the Cornwall deposits embody all the favorable conditions listed on page 16. They occur next to a considerable body of diabase, which exhibits crosscutting relations to the stratified rocks adjacent. They are confined to limestone strata cut by this diabase, and these beds of the limestone are capped both by Paleozoic slates and by Mesozoic carbonaceous shales. Metamorphism of the sort which has affected the limy strata is almost lacking in both of these cap rocks; and though they are baked in the near vicinity of the diabase, the conclusion seems to be justified that they were not permeated by the mineralizing waters to the same extent that the limestones were. It seems a fair assumption that these rocks were from their nature relatively impervious to the solutions which formed the ore, and that they served in a very important degree to prevent the dispersion of these waters and to confine their movements and effects to the limestones and limy shales beneath them, a great body of which had been caught up in the angle between the crosscutting dike on the north and the sill extending out toward the south. There is every reason to believe that the great magnetite deposit at the Cornwall mines was formerly capped entirely over by beds of sandstone and shale, and that the appearance of the ore body at the surface is due to rather modern erosion. If so, two questions which naturally present themselves are: (1) What part of this deposit is still buried beneath barren rock?

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[a] Cornwall iron-ore mines: Ann. Rept. Geol. Survey Pennsylvania for 1885, 1886, p. 526.

(2) Is it not probable that at other localities in the vicinity there are like deposits which, though not uncovered by natural processes, may be found by exploration?

The Cornwall ore body.—Diamond drilling now (1906) in progress will, if systematically continued, eventually delimit the Cornwall ore body. From a geologic point of view the strata which carry the ore may be expected to run out under the Mesozoic cover toward the south in the form of a wedge, the thin edge of which will be encountered where the sill of diabase, rising toward the south, reaches the unconformable surface between the ore-bearing strata and the overlying carbonaceous shales (Pl. III). That magnetite should continue to form so large a proportion of the rock in this direction as it does near the crosscutting dike seems improbable from the theory which has been stated concerning the origin of the ores.

Just west of the Grassy Hill mine the diabase is seen on the surface to trend directly across the strike of the ore-bearing strata and to come into contact with the overlying slate, which is exposed on the north slope of the little knoll west of the Mount Hope wagon road. It seems possible that the limy beds which elsewhere carry the ores may be present beneath this patch of slate, but farther west, where the carbonaceous shales appear in contact with the diabase, the sill seems to be entering this group of beds, so that in this vicinity there is no place south of the dike for the limestone beds to be present except beneath the sill. Starting from a point about 1,000 feet west of the Mount Hope wagon road, where the carbonaceous shale overlaps the slate and comes into contact with the diabase, an irregular line drawn to the southern edge of the ore-bearing strata, when the position of this edge is determined by the drill, will indicate the general limit of these strata south and southwest of Grassy Hill.

East of the railroad and south of the diabase hook which forms the south side of Big Hill, the ore-bearing strata should be present just beneath the rather thick cover of surface débris. Slates appear on the hill slopes north of the eastern part of Miners village, and as these beds are known to lie stratigraphically above the limy beds, the latter are probably in contact with the diabase dike at a moderate depth beneath the capping of slate.

The slates continue as a narrow band from Miners village to the Rexmont-Overlook road. The presence or absence of the uppermost strata of the valley limestone immediately beneath the slate, and, if present, the thickness of the mass, are dependent on the local existence of a direct connection between the dike and the sill and on the depth at which they join. It is evident that if a connection between the sill and the dike exists just beneath the slate there can be no limestone above the sill, and that the deeper the connection the thicker will be the mass of limestone caught in between the dike and the sill. However far the limestone strata may extend along the southern wall of the dike, which trends northeastward from Miners village, just so far are the structural relationships between the different sorts of rock similar to those which have favored the deposition of ore at the Cornwall mines. All of this ground, as far as the road leading from Rexmont to Overlook, is regarded as likely to contain a continuation of the Cornwall ore bed and to warrant such expenditure as would be required to prospect it adequately. (See Rexmont-Overlook section, Pl. III.)

To summarize, it seems that exploration should be extended along the strike of the deposit for about 1,000 feet toward the west and for at least 5,000 feet toward the east.

Near-by deposits.—In regard to the possibility that similar deposits may occur in other localities, it may be said that from the geologic point of view they may very well exist in several places.

East of the Rexmont-Overlook wagon road the southern edge of the Cornwall diabase dike exhibits a crosscutting contact with the Mesozoic beds as far as the first of the three creeks which afford Lebanon's water supply. Here outcrops of slate on the western bank of the stream and next to the diabase presumably correspond with the slate occurring in Mill Ridge and on the opposite or south side of the dike in the neighborhood of the Cornwall mines. On the ridge above this outcrop Mesozoic rocks are found, and the surface of overlap or unconformity lies somewhere between.

The next ravine to the east has been dammed to form a collecting reservoir, along the shores of which flat-lying strata of shale and limestone are well exposed. During the construction a mass of magnetite, which, though it proved to be a pocket, is said to have furnished 500 tons of ore, was encountered in an excavation on the east side of the creek below the dam. From what may be seen at present, it is evident that this pocket of ore occurred between the wall of the diabase dike and limy strata lying just under the overlapping Mesozoic beds. All the sedimentary rocks are considerably metamorphosed, silicate minerals and small segregation of specular hematite being largely developed in the Mesozoic strata for several hundred feet to the south.

Several years ago the Lackawanna Iron and Steel Company put down three test holes in this vicinity, hoping to develop a workable deposit of magnetite. Hole No. 1 was situated a short distance north of the excavation referred to above, No. 1a about 125 feet farther north, and No. 2 on the ridge about 300 feet east of the excavation and about 120 feet above the creek. The following records of these holes have been furnished by the company:

Records of drill holes near collecting reservoir.

HOLE No. 1.

	Feet.
Earth	4½
Diabase	141½
	146

HOLE No. 1a.

	Feet.
Earth	10½
Diabase	91½
	102

HOLE No. 2.

	Feet.
Earth	41
Soft sandstone	26½
Diabase	54½
White limestone	24
Diabase	27
	173

The configuration of the surface is such that hole No. 2, though 173 feet deep, penetrated only 51 feet below the level of the stream. Two interpretations may be placed on the section determined by hole No. 2—that the two bodies of diabase are wedges from the main dike extending out into the stratified rocks, or that there is here merely a waving contact between the dike and the stratified rocks penetrated by it. A hole situated 100 feet or more farther south might be expected to encounter a greater thickness of Paleozoic limestone, and there is the possibility that certain layers might be impregnated with magnetite. On the whole, in spite of the unfavorable result of the tests mentioned above, it seems that it may yet be worth while to make further explorations along the south side of the Cornwall dike from the reservoir westward to the Rexmont-Overlook road, and, as already suggested, thence to Miners village. In all probability a bore hole situated 100 or 200 feet south of hole No. 2 on the ridge above the reservoir would penetrate a considerable thickness of Paleozoic limestone beneath the overlapping Mesozoic beds, and there is no obvious reason why certain layers of the limestone may not be replaced by magnetite.

Eastward from the reservoir, where the pocket of ore was found, the limestone lying beneath the Mesozoic beds can not extend far before being cut by the dike, which within a short distance turns southward into the Mesozoic area and changes from a strongly cross-cutting dike to a sill following the bedding of the Mesozoic rocks.

In all probability a bore hole or shaft less than 50 feet deep located above the diabase in the ravine southeast of Rexmont would reveal slate or limestone, either one of which if present would warrant deeper exploration, even if no ore were discovered in the uppermost layers of the limestone. A fact which would seem to mark this as a promising place for prospecting is the occurrence of ore on the opposite side of the diabase dike at the old Doner mine northeast of Rexmont.

The southern border of the Cornwall diabase dike westward from its junction with the sill southwest of Cold Spring crossing shows a strongly crosscutting contact with massive Mesozoic sandstones. Between this contact and the outcrop of the diabase sill to the south no detailed observations have been made, so that little definite information concerning the structure of the area of Mesozoic rocks lying north and south from the Cornwall and Lebanon Railroad is at hand. However, red sandstone beds exposed near the railroad crossing one-half mile northeast of Mount Gretna station show a dip of about 25° N., and the contour of the west edge of the sill between the mountain known as Governor Dick and the railroad west of Cold Spring crossing likewise indicates a strong inclination of the strata in a northerly direction. Furthermore, only northerly dips are observed south of the railroad along the outcrop of the sill, and it is fairly assumable that the whole block between the two bands of diabase is rather strongly tilted in this direction. If this is accepted as a fact, the group of carbonaceous shales would nowhere meet the crosscutting dike less than 100 feet below the contact line as seen on the surface, except within a few hundred feet from the point where the southern edge of the dike crosses the wagon road west of Cold Spring. As the sill is known to lie in the carbonaceous shales for a long distance westward from the headwaters of Chickies Creek, and also, as it follows these strata both east and west to Cold Spring crossing, it seems most likely that it continues to occupy this position beneath the Mount Gretna block all the way from the southern outcrop to its buried junction with the feeding dike. This probability points to the failure of explorations which might be undertaken between the Cornwall-Colebrook road and the diabase dike, with the expectation of locating limestone strata in contact with the diabase dike, unless the search be extended beneath the sill of diabase.

Along its northern edge the diabase dike is bounded in different parts of its course by four distinct sets of strata. On the extreme west its northern wall is formed by Mesozoic sandstones for a distance of 1¼ miles to a point a short distance west of the wagon road leading from the Horseshoe pike to Mount Gretna (Pl. II). From this place to the next north-south road the bounding rock is evidently limestone, though the line of contact is completely obscured by a cover of surface débris. The boundary has been represented on the map by a random line, the accuracy of which might possibly be improved by more detailed examination than has as yet been made in this vicinity. On general principles this contact may be included among favorable situations for the occurrence of iron ore, though but little emphasis is placed on the suggestion in view of the very slight study which has been given to the locality. Should the surface wash prove to be as deep as it seems to be at first glance, failure to have discovered float ore in tilling the fields can not be regarded as a strong argument against the possibility of ore masses being present in the limestone near the wall of the intrusive dike. The only one of the five features favorable to ore segregation mentioned on page 16 which seems lacking in this vicinity is an impermeable cap rock over the strata lying adjacent to the diabase. At the same time the limestones do not include the strata immediately beneath the slates which comprise the ore-bearing beds at Cornwall.

Farther east there is an extensive patch of carbonaceous shale between the valley limestone and the diabase. Being identical in appearance with the Mesozoic black shales in the railroad cutting on the south side of the dike, within the narrow angle between the dike and the sill, these beds are supposed to belong to the same horizon. They lie nearly horizontal, and are supposed to rest directly upon the limestone or possibly in part upon slate, as do similar beds just south of the ore banks. Every geologic consideration points to this as good prospecting ground. It may be that slates (corresponding to those which outcrop in the wagon road one-half mile southwest of Bismarck) lie between the carbonaceous shale and the limestones in the vicinity of the diabase contact, but somewhere at no great depth beds of limestone belonging to the same horizons as those which have been converted into ore at the Cornwall mines must come into contact with the intrusive diabase. Capped as these beds are by strata only slightly permeable by circulating waters, the conditions would seem to be very similar to those which led to the production of the Cornwall deposit. If the boundary between the shales and the diabase can be taken to indicate the general shape of the northern wall of the dike, there is here an embayment from the north resembling in a way the one from the south, which is occupied by the Cornwall deposit.

From the Bismarck-Mount Hope road to Rexmont the Cornwall diabase dike is bounded on the north by slates, which occupy a band 300 to 400 feet wide along a line of hills known as Mill Ridge. These slates were assigned by Lesley and D'Invilliers to "Formation No. III" of the Pennsylvania Paleozoic section, and they were regarded as resting conformably upon the limestones of "No. II," with a generally rather low dip toward the south. These suggestions seem entirely correct, and it is concluded that as far as these slates extend east and west along the north side of the diabase dike the uppermost beds of the valley limestone, or "Formation No. II," must come into contact with the diabase at a very moderate depth and offer a favorable condition for the existence of iron ore. Though this suggestion is made entirely on the basis of the principles set down on page 16, it finds strong corroboration in the fact that ore occurs just beyond the eastern outcrops of the slate at the old Doner mine. The strata in which the ore occurs at this point are evidently to be included among the uppermost layers of the valley limestone, and their contact with diabase, though hidden by surface wash, can not be far distant from the mine. It is believed that the geologic features of the Doner mine are essentially those which exist beneath the surface for more than 2 miles westward from Rexmont, and there is every indication that the rocks are identical in stratigraphic position with those which contain the great deposit of ore in the Cornwall mines. Separated from the mines only by the dike of diabase held to be responsible for the segregation of iron in the deposits already known and worked, this ground would seem worthy of systematic exploration.

From the north-south road leading to Rexmont as far eastward as Horst's mill, deep wash derived from the near-by hills completely hides the northern edge of the diabase dike, and it is only at the Doner mine that rocks near the contact are exposed at all, and even here nothing definite can be made out regarding the attitude of the strata. The mine is said to have furnished 5,000 tons of ore similar in every way to the surface ore at the Cornwall banks but occurring intermixed with loose sand. The pit from which the ore was mined is now completely caved in, but seems to have been 40 or 50 feet wide and perhaps 250 feet long. North of the workings bowlders of hard magnetite are found in the soil over an area 700 to 800 feet square. This material is supposed to be float from the Doner deposit. Several years ago two or three holes were drilled on this property, but beyond the report that no attractive ore body was encountered records of this work have not been procured. From the fact that the old workings extended east and west, three possibilities may be considered as to the shape of the ore mass in its original state, before it became broken down by surficial weathering, and it is believed that negative results at this place are not to be considered as finally adverse to the presence of a workable ore body until tests have been carried out with reference to each of these possibilities: (1) The impregnated rock may have been a layer in the limestone capped over by a barren stratum. If, then, the beds have a southward dip the edge of the diabase may lie some distance to the south; (2) the ore may have formed along the wall of the dike as a replacement of a limited amount of limestone in contact with the intrusive rock; in this case the diabase would be found very near the old workings; (3) the ore may have been deposited along the walls of a fissure running parallel with the wall of the dike, but at some distance from it. The deposit of ore at the old Carper mine, 8 miles west of Cornwall, seems to have had this origin.

The contact of diabase with the valley limestone eastward from the Doner property to the main reservoir of the Lebanon waterworks is hidden by a heavy apron of sandstone débris, so that the line representing the boundary on the sketch map is only an approximation. Though ore may occur along this contact, prospecting would hardly be taken up unless favorable results had been obtained in some of the more accessible localities suggested above.

MINES WEST OF CORNWALL.

Near the edge of the Mesozoic belt between Cornwall and Susquehanna River there are two minor occurrences of magnetic ore—one at the old Carper mine in Lebanon County, about 1 mile southeast of Mount Pleasant, the other in Dauphin County, about 2 miles southeast of Hummelstown.

CARPER DEPOSIT.

The Carper deposit, from which 1,500 tons of ore have been mined, appears to lie in a fault break, which may be regarded as a westward extension of the fissure which holds the Cornwall diabase dike. North of the ore pit the rocks are Paleozoic limestone, while to the south are baked shales, followed by diabase. The shales were regarded by Lesley and D'Invilliers as equivalent to the slates of Mill Ridge occurring at Cornwall,[a] but to the writer they seem to belong with the Mesozoic strata.

The diabase which outcrops south of the mine is a sill which follows the Mesozoic strata. The sill strikes northeast and southwest, and dips toward the northwest. The trend of the diabase is diagonal to the course of the fault, and the intrusive rock does not continue north of the break. On the geologic map (Pl. II) it has been represented as ending at the fault, though exposures are not sufficient to show that it actually extends as far toward the northeast. Toward the southwest the diabase widens in outcrop and is known to constitute a large mass. The sandstones and shales near it are strongly baked or indurated, and are also bleached to a considerable extent. The occurrence of the ore in the fault fissure, the presence of the igneous rock near by, and the fact that the inclination of the diabase mass toward the north and northwest would carry it beneath the place where the ore outcrops make it probable that the deposit was formed by solutions circulating along the fault break and impelled by the heat of the buried diabase. If the true relations of the deposit are as here suggested, the ore should persist in depth and should also occur at other points along the fault both east and west of the old mine. Though the exact position of the fault is hidden by overwashed débris from the adjacent hills, no serious difficulty would be experienced in finding it by means of excavations. This fault appears to be the westward extension of the fissure occupied by the crosscutting mass of diabase at Cornwall.

Iron ore is reported to occur about 1 mile southwest of Mount Pleasant, where some prospecting was done several years ago. This

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[a] Ann. Rept. Geol. Survey Pennsylvania for 1885, 1886, p. 544.

locality was not found, and it is not known that the ore is of the Cornwall type. In this neighborhood the Paleozoic limestones contain several masses of intrusive diabase, so that it would not be at all surprising to find ore like that of the Cornwall mine.

HUMMELSTOWN DEPOSITS.

The deposits 2 miles southeast of Hummelstown are situated well within the belt of Mesozoic rocks on the east side of Waltonville Brook. The ore, consisting of magnetite and specular hematite somewhat contaminated by pyrite, occurs in pockets, several of which have been worked out, but from what may be seen the deposits could hardly have been of any great importance. A small amount of garnet occurs with the ore minerals. The old workings are in the valley of a small stream and extend in a general east-west direction for a distance of about 2,500 feet. Except along the wagon road there are few exposures of rock in place in the vicinity. North of the ravine in which the ore pits are situated the strata stand in nearly vertical position, but south of the ravine the beds of sandstone have a northerly dip of about 20°. From these observations it is evident that the deposits occur adjacent to and probably in part along a strong fault break. Everywhere in the vicinity of the fault the sandstones are greatly bleached and indurated, as similar rocks are elsewhere in the neighborhood of diabase masses, and, though no outcrops of the igneous rock appear in the immediate vicinity, it is believed that diabase must be present at some unknown depth beneath the surface and that waters heated by this rock, or perhaps derived from it, were responsible for the general metamorphism and for the segregation of the iron ores.

Though the deposits are of interest to the student of ore genesis, it does not seem that they offer sufficient encouragement for more extensive exploration.

BERKS COUNTY DEPOSITS.

WHEATFIELD GROUP.

GENERAL DESCRIPTION.

The Wheatfield group of mines, with which the Ruth mine is here included, is situated about 7 miles southwest of Reading and a short distance southeast of Fritztown station, on the Columbia division of the Philadelphia and Reading Railroad. (See Pl. VI.) In their geologic features the deposits of iron ore at this place show certain striking resemblances to the Cornwall deposits 20 miles to the west. The ores occur as irregular masses, having a general layer-like form, interbedded with limestone strata, but the ore bodies are numerous rather than large, and lack of persistency is a marked characteristic. In respect to stratigraphic position, the strata which carry the deposits do not correspond with those of the Cornwall mine, for they apparently belong at the base of the Paleozoic limestones ("No. II" of the Second Pennsylvania Survey), as at the Raudenbusch and Island mines near Reading and at Boyertown. This conclusion regarding the equivalence of these strata is not based on a critical study of the question by the present writer, but is deduced from recorded descriptions by D'Invilliers and from the distribution of the Paleozoic formations as exhibited on his geologic map of Berks County.[a]

Like the deposits at Cornwall, Reading, and Boyertown and at the Jones mine, the Wheatfield deposits occur very near the overlap of Mesozoic beds and adjacent to a large intrusion of diabase.

DIABASE INTRUSION.

The ore-bearing strata appear at the surface along the east and north sides of a roughly rectangular area of sedimentary rocks, forming a northward embayment in the principal diabase mass of the district. The greater part of this area, which is nearly a mile long and three-fourths of a mile wide, is covered by Mesozoic rocks. The older strata, in which the ore occurs, are restricted to a band 150 to 250 yards wide next to the curving edge of the diabase intrusion. The south edge of this band is formed by the overlap of the Mesozoic beds, south of which there is an outlying, irregularly shaped mass of diabase opposite the embayment in the main intrusion. (See Pls. V and VI.)

The mass of diabase that curves around the Wheatfield group of mines constitutes the western termination of an intrusion which extends 7 miles eastward to Schuylkill River and thence somewhat more than 10 miles in a southeasterly direction along the western side of the broad Schuylkill Valley (Pl. V). The outcrop of this diabase is from one-third mile to 1 mile wide. Throughout the greater part of its course it lies wholly within the Mesozoic area, where it has the form of a sill, closely following the stratification of the incasing rocks. Near the Schuylkill, however, where its course changes from east to southeast, and also near the Wheatfield mines, marked crosscutting may be observed, and Paleozoic as well as Mesozoic rocks come into contact with the diabase. It is in these Paleozoic strata near the diabase that the ore deposits occur at the Fritz Island and Raudenbusch mines south of Reading, and at the Wheatfield mines 7 miles farther east. (See cross sections, figs. 1, 2, and 3.)

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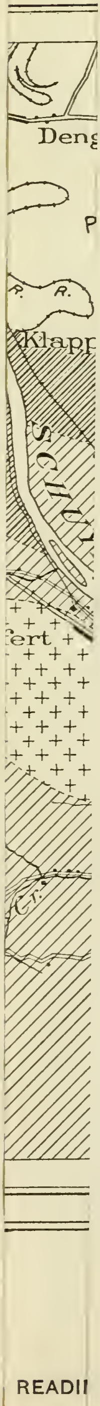
[a] Geology of the South Mountain belt of Berks County: Second Geol. Survey Pennsylvania, Rept. D3, pt. 1, atlas, 1883.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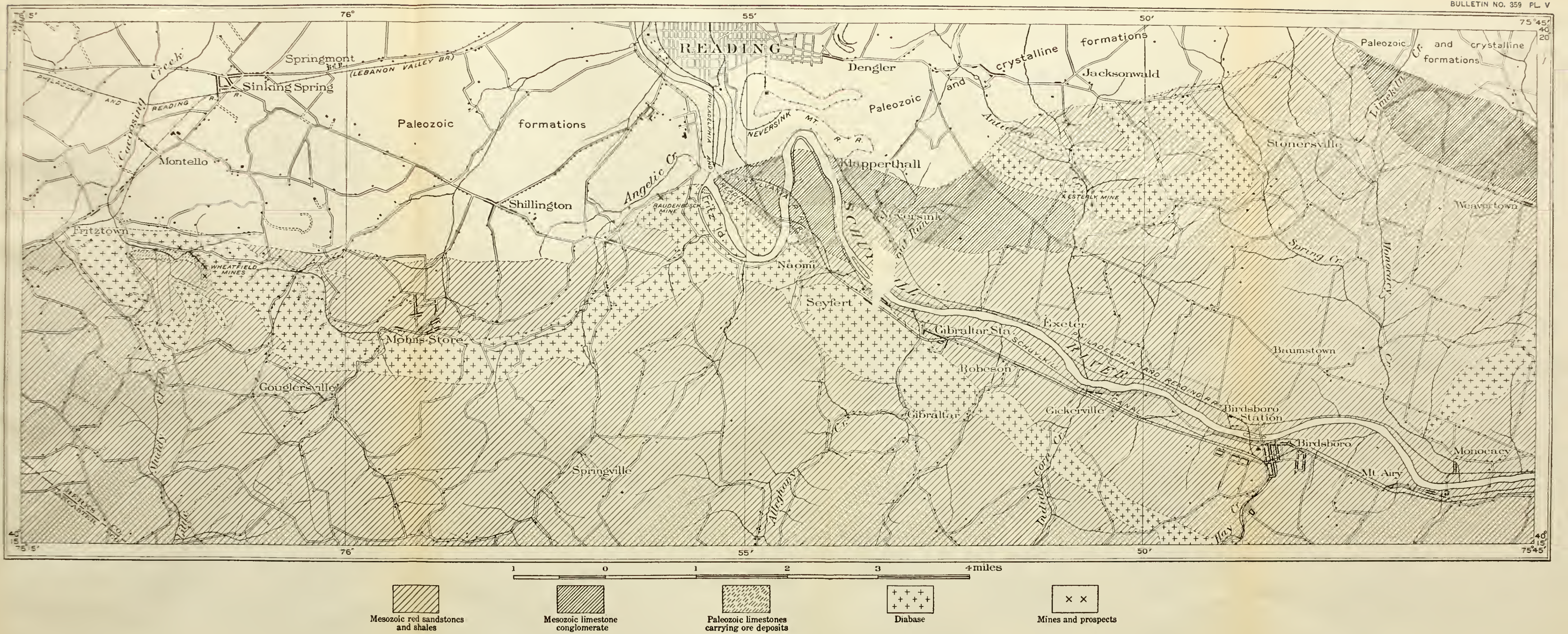


GEOLOGIC SKETCH MAP OF DISTRICT SOUTH OF READING, BERKS COUNTY, PA.

CHARACTER OF THE ORES.

The Wheatfield mines have not been extensively worked for more than twenty years, though small amounts of surface ore have been extracted from time to time, the last mining having been done in 1905 and 1906. The ore to a depth of 30 or 40 feet is reported to be invariably soft or earthy, evidently as a result of the ready decomposition of the original ore, owing to the presence of considerable pyrite. These soft ores have been desired by ironmasters for mixtures, but the unweathered or hard ores seem to have found little favor, as they are at once of rather low iron content and so high in sulphur as to require roasting before they can be used in a blast furnace. Apparently for this reason, and because the deposits are not large or even persistent, these mines have not been more systematically developed.

STRUCTURE OF THE ROCKS.

Most of the old workings of the group are situated near the east side of the area of sedimentary rocks which sets back from the south into the diabase dike and south of the east-west public road which follows the upper valley of Cacoosing Creek. About a dozen open pits have been operated at various times, and in addition many slopes and several vertical shafts. Across the creek, on the north side of the wagon road, there is an opening, formerly known as slope No. 1, and in 1905 some surface ore was taken out by means of a slope located a short distance east of these old workings. The Ruth mine is situated about one-half mile west of slope No. 1, about 200 yards east of the direct road from Fritztown to Adamstown.

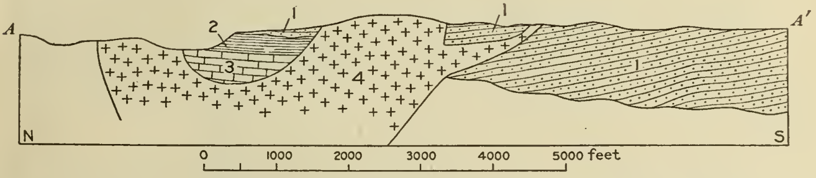


FIG. 1.—North-south structure section 400 feet east of Ruth mine, Wheatfield group (along line *A–A′*, Pl. VI). 1, Mesozoic beds; 2, Paleozoic slate; 3, Paleozoic limestone; 4, diabase intrusion.

In the more southerly Wheatfield workings the strikes of the strata run nearly north and south, as shown both by the direction in which the pit workings extend and by the beds of limestone exposed in the old excavations; but farther and farther north the strata turn more and more toward the northwest and finally run nearly east and west at slope No. 1. Dips are here invariably toward the concave edge of the curving band of ore-bearing rocks and away from the wall of the surrounding diabase. At the Ruth mine, where the strata are fairly well exposed in the open cut, the stratification is found to be nearly horizontal, though the ore body is reported to dip 30° S., indicating that it is not conformable to the bedding of the inclosing rocks. Both here and at slope No. 1 the foot wall of the ore is diabase and the immediate hanging wall is limestone or limestone breccia. In both places also the limestone capping above the ore is overlain by slate, and in the hills south of the Ruth mine débris of this slate and a few shallow excavations show it to have a thickness of about 80 feet. At slope No. 1 its thickness can not be determined and the area which it covers can not be defined, owing to lack of exposures.

No stratum corresponding to the slate mentioned above has been encountered in the workings situated south of the public road, but the changing strike of the bedding toward the north along the ore band toward slope No. 1, together with the fact that the limestone layers in the Ruth mine, in slope No. 1, and in several of the southern workings are similarly composed of fragments, would make it appear that the strata occurring in the southward-trending leg of the strip in which the ore is found lie stratigraphically below the bed of slate. In this case, as the beds dip toward the west, it is possible that the slate may be present west of the main workings beneath the surface capping of the Mesozoic sandstones.

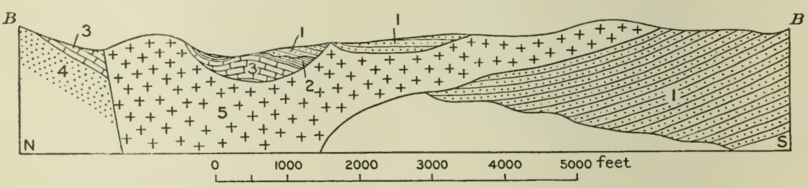
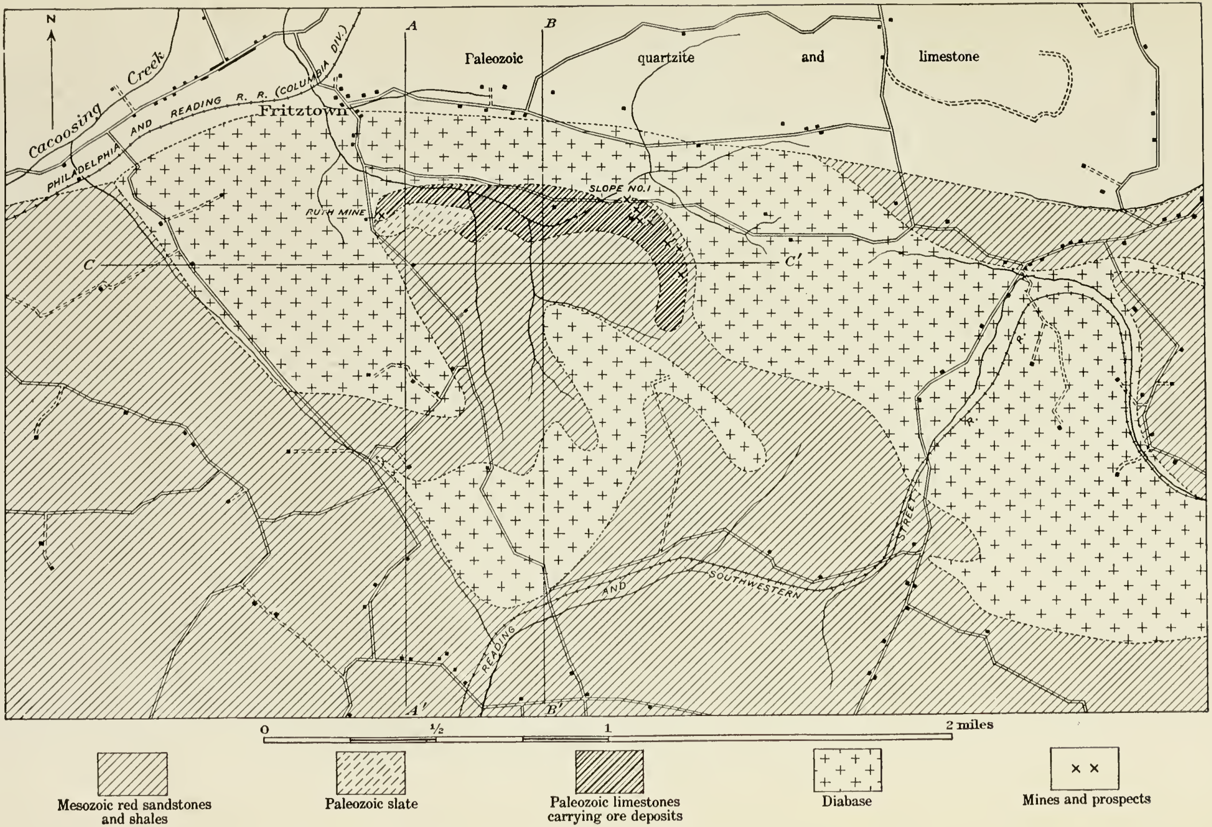


Fig. 2.—North-south structure section near slope No. 1, Wheatfield group (along line *B–B′*, Pl. VI). 1, Mesozoic beds; 2, Paleozoic slate; 3, Paleozoic limestone; 4, Paleozoic quartzite; 5, diabase intrusion.

Two beds of limestone, one solid and the other made up of fragments, are exposed, with low southerly dips, in the creek bed between the two main tributaries from the south (Pl. VI). These strata are supposed to correspond with those in the main Wheatfield workings, and their presence in this place suggests that the slate at slope No. 1 can not be connected by continuous outcrop with the slate at the mine. The dips at the two places are not in accord, and it may very well be that there is a fault between.

In the bed of the more westerly of the two northward-flowing brooks (Pl. VI), 500 or 600 feet above its junction with the main creek, green clays containing disseminated crystals of magnetite are found. This material resembles some of the earthy material from the mines, and with little doubt it represents the weathered crop of a stratum belonging to the set of beds which carries the ore deposits



GEOLOGIC SKETCH MAP OF VICINITY OF WHEATFIELD MINES, BERKS COUNTY, PA.

1½ miles to the east. Appearances also favor the opinion that this horizon is nearly the same as that of the ore-bearing beds at slope No. 1 and at the Ruth mine. Outcrops of Mesozoic sandstone are seen on the east bank of the brook near by, and 1,000 feet or so upstream red shales and sandstones are present, striking N. 10° E. and dipping 30° W. In the bed of the eastern brook the strike is the same, but the dip is only 10° W.

The attitude of the rocks in the several places mentioned above shows that there is a strong unconformity between the Mesozoic sandstone and the set of strata which carries the ores; this is also shown by the fact that in some places the younger beds rest directly upon the limestones, whereas in others, as on the knoll south of the Ruth mine, they were deposited upon the stratigraphically higher slate. This relation makes it evident that none of the rocks which incase the ore can belong to the Mesozoic, though the contrary was believed to be the case by Rogers, whose opinion was accepted by Willis,[a] and by D'Invilliers[b] at the time his report upon the geology of Berks County was written.

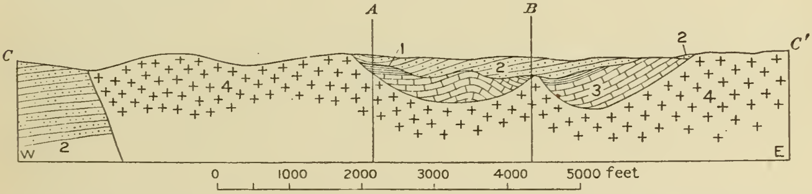


FIG. 3.—East-west structure section 1,000 feet south of public road, Wheatfield group (along line *C–C'*, Pl. VI). 1, Paleozoic slate; 2, Mesozoic beds; 3, Paleozoic limestone; 4, diabase intrusion.

The rocks in the neighborhood of the Wheatfield group of mines are sufficiently exposed to reveal very complicated geologic relations without being well enough shown to make possible the determination of these relations in detail. Information is lacking which might suggest the shape of the diabase intrusion underground or which might lead to an estimate regarding either the thickness of the calcareous beds which carry the ore deposits or the nature of the strata which lie below them. All these points must be known in at least a general way before geologic cross sections of any practical value can be drawn. The sedimentary rocks of the area which sets back into the main dike of diabase may be partly or entirely underlain by a mass of igneous rock forming a connection between the main cross-cutting dike and the southerly body of diabase, or it may be that the surrounding masses of diabase approach each other only at rather

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[a] Willis, Bailey, Tenth Census, vol. 15, p. 228.

[b] Second Geol. Survey Pennsylvania, Rept. D3, 1883.

great depth. Whatever the actual relations may be, they can not be made out from features observed on the surface, and their determination must await information furnished by diamond-drill explorations.

Systematic study of the Paleozoic formations of the district might definitely fix the position of the Wheatfield ore-bearing strata with reference to the quartzite which occurs in the ridge just north of the diabase intrusion, and furnish a basis for estimating their thickness in the vicinity of the mines. These determinations would be, however, of small practical value compared with data which might be procured incidentally if a few well-located holes were drilled to test the downward extension of the ore-bearing strata and the degree to which they are mineralized in depth.

PRACTICAL CONCLUSIONS.

Though so much is indefinite or unknown regarding the geology of the Wheatfield deposits, yet the number and distribution of the ore beds already worked, the observable structure of the strata in which the deposits lie, and the general relations which they bear to the diabase mass and the overlying Mesozoic strata, when considered together, suggest that the expense of a certain amount of exploration in the northern half of the sedimentary embayment would be justified by the chances of locating important bodies of ore. As already stated, the impression gained from strikes and dips in the band of ore-bearing strata, and from the occurrence of the two patches of slate at the Ruth mine and slope No. 1, is that the strata which carry the ore beds in the southern group of mines lie stratigraphically below the slate. At the Ruth mine the slate and limestone beds lie nearly horizontal, and it seems that a hole drilled anywhere between this old opening and the first northward-flowing creek to the east must penetrate the whole set of ore-bearing beds unless part of them are cut out beneath by the intrusive diabase. The proximity of the diabase would lead to the expectation that beds suitable in composition for impregnation with iron minerals would be, in part, at least, converted to ore. Southward from the Ruth mine the limy strata are overlain at first by slate and finally by sandstone as well, but beneath perhaps 150 feet of this capping they doubtless come into contact with the cross-cutting mass of diabase which forms the bold hills west of the wagon road, and the vicinity of this contact is again favorable to the presence of ore.

It is probable that under the meadow which extends along the creek the set of ore-bearing strata would be encountered immediately beneath the valley wash, as indicated by the beds of limestone outcropping between the two northward-flowing tributaries. Furthermore, the southward dip of the diabase wall in slope No. 1 suggests that these strata will be found resting upon the inclined floor of the intrusive rock in a manner reproducing in a way one of the striking features of the Cornwall deposit.

From a practical standpoint deep prospecting in the vicinity of the main workings of the Wheatfield group would seem to offer somewhat better chances for a successful outcome than explorations elsewhere in the neighborhood, because the presence of ore in so many places reveals the fact that there has been a very important amount of mineralization. With reference to the theory that the ores of the Cornwall type have been produced by replacement of limy strata induced by the intrusive diabase, it is more than likely that the mineralizing solutions percolating through the rocks moved away from the hot diabase rather than toward it and at the same time tended mainly upward toward the surface rather than downward toward the source of heat.

This line of reasoning leads to the expectation that the ore bodies coming to the surface along the eastern leg of the band of Paleozoic strata may increase in number as well as in size and persistency as the ore-bearing strata are followed downward along their west and southwest dips.

The practical question whether hard iron ores of the grade thus far found in the unweathered portions of the Wheatfield deposits, if discovered in comparatively large amount, would be worth developing at the present time lies beyond the scope of the present investigation. The writer believes, however, that the fact that the owners have never attempted to determine the real possibilities of the property by systematic prospecting can not be taken as evidence that such exploration is not fully warranted as an undertaking likely to give adequate returns on the required outlay.

As already pointed out, the Wheatfield mines, as well as the Raudenbusch and Island mines, which lie about 7 miles to the east, are next to the same mass of intrusive diabase at the only localities where it comes into contact with the Paleozoic formations on the surface (Pls. V and VI). Throughout the interval the diabase has the form of a northward-dipping sill outcropping parallel with and from one-half to 1 mile south of the northern edge of the Mesozoic belt. Somewhere beneath the surface the sill must reach the Paleozoic rocks beneath the cover of Mesozoic shales and sandstones, and it seems very likely that here its form changes to that of a dike. If this be the case, conditions favorable for the occurrence of ore may exist along the walls of the dike wherever limy Paleozoic strata come into contact with it. Probably the most favorable condition would be realized if strata which correspond in stratigraphic position with those at the Wheatfield mines could be found next to the dike.

Though the broad suggestion that buried ore bodies may exist in the situation indicated seems entirely valid, the chances of locating deposits of value are regarded as too remote to be seriously considered from a practical standpoint. Prospecting along this strip of country north of the diabase sill is therefore not recommended except where the intrusion approaches the northern edge of the Mesozoic belt, and even here the possibilities can hardly be regarded as very encouraging.

For $2\frac{1}{2}$ miles east of Fritztown station the diabase is in contact with Paleozoic rocks, but beyond the fact that the hills north of the diabase are composed of quartzite (in one place dipping 50° S.), nothing concerning the local geology can be stated at the present time, because the country has not been examined in detail. If limestone beds are present above the quartzite, and if the general dip of the formations is toward the south, so as to carry them down beneath the diabase, the vicinity of the contact would seem to offer favorable conditions for the occurrence of ore masses like those which are present immediately opposite, on the south side of the dike.

RAUDENBUSCH MINE.

Describing the Raudenbusch property in 1858, H. D. Rogers says:[a]

> About half a mile west of the preceding [Island mine] is the Raudenbusch mine, which, we are informed, yields its proprietors at the Phoenixville furnaces 5,000 tons of ore per annum. The vein ranges a little north of east. Its foot wall is white metamorphic limestone, or marble, and its hanging wall or roof a dull sea-green, serpentine-like rock which on exposure soon crumbles down like ordinary shale. The vein, dipping 36° S., is followed by a slope 280 feet beneath the surface. At the bottom gangways are driven 200 feet west and 400 feet east to a fault cutting out the vein. A higher level, 160 feet from the surface, is driven 300 feet east. The ore is now taken from this level. Like all others, this vein is exceedingly variable; while wholly or almost entirely absent in some places, in others it has been found 30 feet thick. Its average bulk will not exceed 12 feet. The gangue stone of the ore is a light-blue rotten limestone, from which the ore is scarcely distinguishable except by its greater weight and deeper tint. Of the entire ground wrought, about one-half of the material is sufficiently rich in iron for the furnace; the remaining rubbish is used as stopping in the old workings.

D'Invilliers states:[b]

> There are two small shafts on the property, one of them 50 feet deep. On the dump are seen gray, greenish, and black limestones very much decomposed, some of which may represent the presence of the brecciated Mesozoic "all sorts" [i. e., limestone conglomerate] so characteristic of this part of the range, but none such is seen in place on the surface. * * * Most of the limestones seem altered, which is accounted for by the proximity of the trap dike [diabase] to the south. This trap shows in the 50-foot shaft, as also some light-gray to white limestone, the latter showing a slight coating of hematite.

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[a] Geology of Pennsylvania, vol. 2, 1859, pp. 716–717.

[b] Geology of Berks County: Second Geol. Survey of Pennsylvania, Rept. D3, 1883, pp. 342–343.

To the present writer it seems unlikely that any Mesozoic rocks, either limestone conglomerates, shales, or sandstones, are present north of the diabase in this vicinity. The only rock now to be seen at the surface is white limestone exposed in the farm road that gives access from the public road to the fields just north of the old mine. South of the wagon road, on the slope of the hill, a shaft not mentioned above was sunk through a green shaly rock, probably the same as that referred to by Rogers as forming the hanging wall of the ore. This material seems to be of sedimentary origin, and it evidently lies between the ore and associated limestone beds and the mass of diabase that forms the adjacent hill. The surface distribution of the diabase is shown on the sketch map (Pl. V), from which it may be seen that it is a northward offshoot from the intrusive sill described in the discussion of the Wheatfield mines. In relation to the Mesozoic strata, this northward-reaching arm is evidently crosscutting, though in respect to the Paleozoic strata it may be locally following the bedding, as is suggested by the southerly inclination of the old mine slope.

It seems a reasonable conclusion from what is known concerning the distribution of quartzite, slate, and limestone along the south edge of the Paleozoic area that the Raudenbusch deposit, like those of the Wheatfield group, lies in the beds of passage between the quartzite and the limestone. Crumpled slate is exposed in a little knoll about 1½ miles southwest of the mine and one-half mile west of the Center Hotel; just west of this knoll quartzite appears with dips toward the southeast beneath the slate. In the road-metal quarry along the wagon road on the east side of the slate knoll, Mesozoic conglomerate rests upon the slate, with its stratification dipping gently southward. Half a mile east of the mine southward-dipping quartzite forms the prominent hill south of the reservoirs above the wagon bridge over Angelic Creek. Immediately south of this quartzite knoll, slates and limestones may come in above the quartzite before the diabase is reached, but their presence or absence can not be determined because of the existing mantle of surface débris. It is suggested that other ore beds like the one formerly mined may exist along the northern wall of the diabase both east and west of the Raudenbusch mine. On the west the question could be readily settled by running crosscut tunnels toward the diabase and drifting either along the contact or, perhaps better, along the hanging wall of green slate, which will probably be encountered before the intrusive rock is reached.

Suggestions for prospecting eastward from the Raudenbusch mine will be deferred until after the Island mine has been described.

FRITZ ISLAND AND VICINITY.

ISLAND MINE.

The Island mine is situated 2 miles south of Reading, at the north end of Fritz Island, in Schuylkill River. The old workings are very near the edge of the Mesozoic belt, and are thought to have penetrated the Paleozoic limestone which lies beneath the Mesozoic strata. Large masses of diabase are present in the vicinity and dikes of the same rock were encountered in the mines (Pl. V). The geologic features of the mine may be summarized from the account by D'Invilliers.[a]

The ore was encountered through the washing away of some ground by high water during the winter of 1850–51. In opening the mines and extending the workings underground it was found that the ore occurs in a magnesian limestone, with associated shales of a sea-green color like those at the Raudenbusch mine, and that the ore-bearing strata are capped over by a limestone conglomerate.

Diabase is here and there the foot wall, but beneath the ore there is, more commonly, a decomposed sandstone, regarded as of Cambrian age, and therefore similar to the quartzite outcropping in the knoll about half a mile to the north. The ore pinches and swells, as in the Boyertown mines, the maximum recorded thickness being 22 feet. Horses or wedges of limestone are found with ore occurring on either side. The strike of the deposits is nearly east and west, and though the general dip seems to be toward the north, in places at an angle as great as 40°, locally the ore stands vertical or even dips toward the south. Slope No. 1, beginning on the outcrop, is 231 feet deep, being inclined at the top about 62° and averaging about 46°. Three levels were run eastward from the slope, passing under the bed of the river and under a small island in the eastern channel, known as Yost Island. West of the shaft the two lower levels were carried about 150 feet, which brought them beneath the east end of the open pit (Pl. VII). The gangways are about 60 feet apart, the upper one being about 50 feet below the surface.

Considerable stoping was done above the lowest level. In the bottom of the mine, 125 feet east of the slope, the ore was found to branch and was followed by two drifts which came together 175 feet beyond. Irregularity of dip is shown by the vertical attitude of the vein in the middle level 300 feet east of the slope. Diabase was encountered beneath the ore in all the drifts, and a crosscut from the bottom level revealed a leader of ore on the south side of this dike. The dike is somewhat more than 100 feet thick, and its south wall nearly vertical. The ore lying south of the dike dips to the south and is thought to be the same vein as that opened by slope No. 2 and

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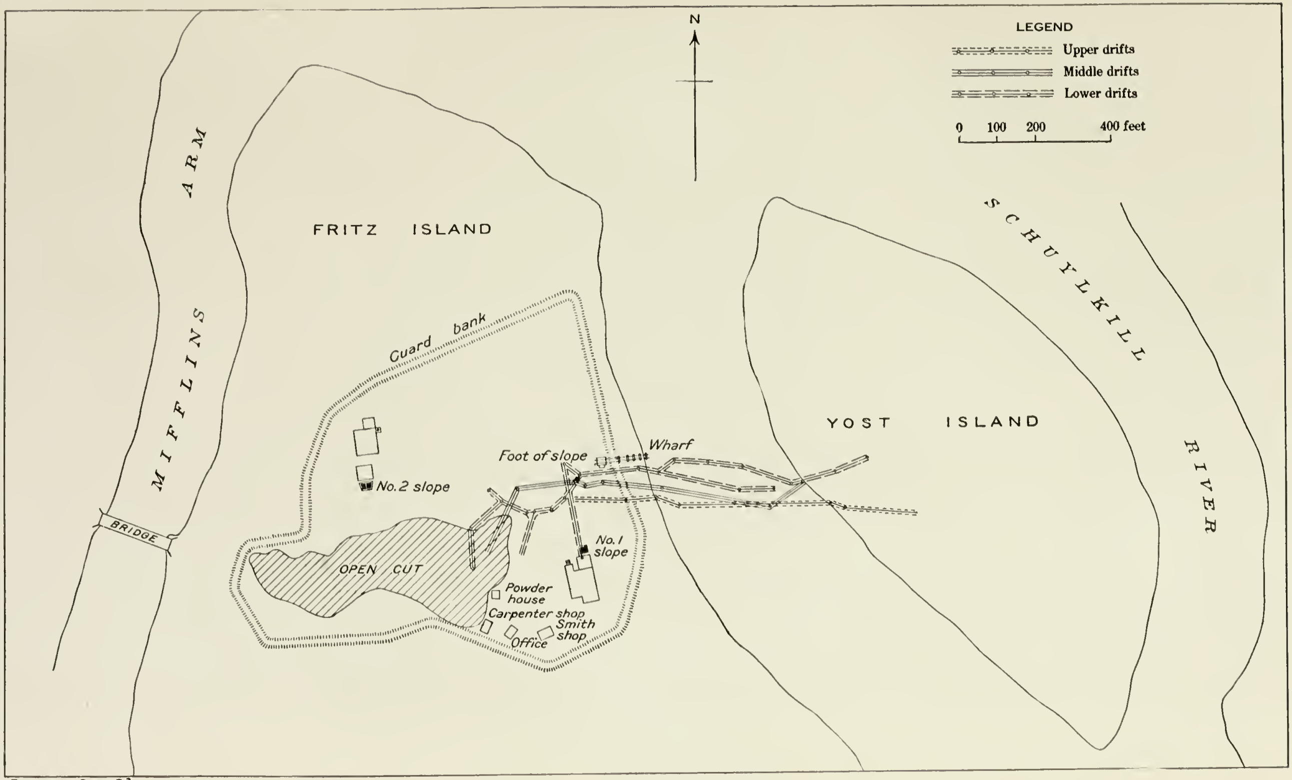
[a] Second Geol. Survey Pennsylvania, Rept. D3, 1883, pp. 333–342.



From atlas to Report D³
Second Geological Survey of Pennsylvania

MAP OF FRITZ ISLAND IRON MINES, BERKS COUNTY, PA.

worked to a depth of about 100 feet above the crosscut from slope No. 1. The position of slope No. 2 is about 300 feet northwest by west from No. 1.

In 1883 slope No. 2, which is sunk through rock, was down 122 feet on a dip of 40° to 55°, averaging perhaps 45°, but the direction of slope is not stated.

The open-cut workings seem to have had considerable importance, although no record has been found concerning the features which they exhibited. The old pit extends east and west and is nearly 300 feet in length.

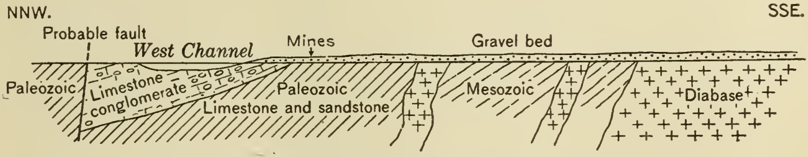


FIG. 4.—Sketch section at north end of Fritz Island.

The average daily production of the mine in 1883 was 25 to 30 tons, amounting to about 10,000 tons per year. At that time only one slope, No. 1, was being operated. The total yield up to 1883 was estimated at 250,000 tons.

The general relations of the different rocks indicated by the foregoing description are shown in fig. 4. Apparently there is a wedge of Paleozoic limestone lying between diabase dikes on the south and northward dipping conglomerate on the north, but it is not known whether the ore bodies followed the bedding of the inclosing rocks or not. On Fritz Island the thin edge of the wedge has been removed by erosion, and the same relation probably exists near the towpath on the east side of the Schuylkill, where, as reported, ore was discovered in a prospect shaft. Farther east, however, the Paleozoic rocks seem to be capped over by Mesozoic strata in some such manner as indicated in fig. 5. In the two figures just mentioned a fault is shown between the Mesozoic and Paleozoic areas, because the northerly dip of the conglomerate makes it difficult to see how this boundary could be formed by simple overlap. At many places the nature of the northern boundary of the Mesozoic is a vexing question, for though overlap is locally observable, elsewhere there is strong evidence of fault displacements of considerable amount.

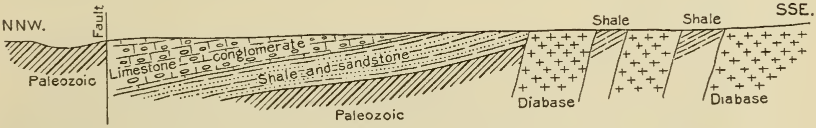


FIG. 5.—Sketch section along river bank east of Fritz Island mines.

Future mining on Fritz Island is not likely, as the property has been acquired by the city of Reading to be used as a sewer farm, but even if otherwise available the fact that the old workings run out beneath the river introduces an element of danger from flooding which might preclude further development. From a purely geologic standpoint it seems that the deposit might be expected to show considerable continuity in depth, for if the ore beds already worked are not actually continuous, others might be discovered by deep prospecting along the contacts of the intrusive masses of diabase.

The statement is made in the report by D'Invilliers[a] that mining toward the east was discontinued somewhere beneath Yost Island because of poor ventilation, so that it may be inferred that ore still remains at this place. The fact that ore was also found on the east side of the river near the towpath is a further indication favorable to prospecting in this direction. The rocks which have furnished the surface débris in the neighborhood are shales, sandstones, limestone conglomerate, and diabase, and the ore-bearing strata can hardly come to the surface except in a narrow wedge-shaped area near the river bank. As the northeast wall of diabase is followed in a southeasterly direction, the limestones are found to become covered by a rapidly thickening cap of the younger strata, so that it seems that any ore bodies existing will be found to lie deeper and deeper toward the southeast. In making the above suggestion it is assumed, as elsewhere in this report, that ore will not occur except near the intrusive rock, and that important bodies are not likely to be found where the diabase is in contact with other than calcareous strata. The only exception to this rule which has been noted is at Boyertown, where the Black vein and the East vein are both some distance away from the diabase intrusion.

EAST BANK OF SCHUYLKILL RIVER.

On the east side of the Schuylkill, as on Fritz Island, the diabase is not a solid mass, two dikes being separated from the main body lying to the south by strips of Mesozoic shale. If these dikes continue downward and penetrate the ore-bearing limestones separately, crosscut tunnels would seem to be justified in order to explore all their walls, and also that of the larger intrusive mass beyond. This supposition is suggested by the occurrence of ore on both sides of the 100-foot dike in the Island mine.

It would seem that if due care is taken to avoid breaking into the old Island mine workings, further prospecting from the east side of the river will be warranted by the probability of finding ore bodies similar to those formerly worked on Fritz Island. The known

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[a] Second Geol. Survey Pennsylvania, Rept. D3, 1883, pp. 337–338.

presence of ore near the river bank would apparently justify a shaft, from which tunnels could be run as suggested above. Prospecting in this manner would probably be more satisfactory than by a series of drill holes.

WEST BANK OF SCHUYLKILL RIVER.

West of the river the presence of deep surface wash makes it impossible to determine whether the fields below the wagon road are underlain entirely by diabase or in part by sedimentary rocks Diabase is exposed opposite the north end of Fritz Island, but from the existence of two outlying dikes east of the river and at least one on the island, all with apparently east-west courses, it may very well be that this outcrop belongs to a mass lying north of the main intrusion. The question whether this is so or not is important and could be settled at slight cost by running two or three short tunnels from the bank of the western channel above the Fritz Island bridge. It is believed that if any other rock than diabase is found there would be a good chance of discovering ore bodies like those of the Island mine by systematic prospecting. It is perhaps not likely that limestone conglomerate will be encountered, but if it should be present it would only be necessary to turn northward and penetrate this cap in order to reach the Paleozoic strata. If any ore should be found it would be desirable to determine how many outlying dikes of diabase exist and to explore carefully all contacts.

ESTERLY MINE.

About 4 miles due east of the Fritz Island mine and 2 miles south of Jacksonwald, on the W. Esterly farm, a small deposit of magnetite was once worked. William G. Rowe, of Reading, is authority for the statement that this mine furnished between 3,000 and 4,000 tons of ore. It was opened to a depth of 125 feet by a 58° slope inclined toward the north, the drifts being run about 250 feet to the east. About 600 feet southeast of the Esterly slope an opening known as the Bishop shaft was sunk for 150 feet and a north crosscut driven for 200 feet, ending in garnet rock. A bore hole from the bottom of this shaft reached limestone conglomerate at about 300 feet.

The Esterly vein lies between a hanging wall of diabase and a foot wall of metamorphosed shale. The diabase is an intrusive sill included in northward-dipping strata. In the neighborhood of the intruded rock there has been considerable baking, and here and there such metamorphic minerals as garnet, hornblende, and magnetite are found. These minerals, with some chlorite, are present in the material on the old mine dump, and the silicates evidently occur in close association with the magnetite of the ore. Some limy material is to be noted, but no pure limestone; it seems, therefore, that this ore was formed by the replacement of shales under the mineralizing influence of the diabase.

The diabase is the outer of two concentric curving sills which follow the bedding of the Mesozoic shales and sandstones, here thrown into a rather sharp synclinal fold (Pl. V). The ore bed lies on the lower contact of the sill and, like it, strikes conformably with the inclosing rocks, nearly east and west, with a dip of about 50° N. The deposit may be imagined to have considerable downward extent, though of course its continuity in this direction can not be affirmed. Along the strike it is rather short, as not more than 100 feet west of the slope carbonaceous and limy shale is exposed along the road, and though the situation is very near the diabase contact no magnetite has been developed.

No other magnetite is known to have been found along either side of this arm of the sill, but Mr. Rowe states that specimens have been plowed up in the fields near Spring Creek, between the northern arm and Stonersville. Though some prospecting was done in this vicinity, no magnetite was found in bed rock. It is possible that the mineral may have been float from a deposit situated near the diabase wall on the hill slopes above the creek, though it may have been derived from a pocket lying in the limestone conglomerate which covers considerable ground on the west side of Spring Creek south of the Reading turnpike.

In this place the strata of limestone conglomerate dip rather steeply to the southwest. This dip would carry them beneath the diabase sill, but the outcrops are so far from those of the diabase that it seems hardly likely that any important body of ore will be found in this rock, at least near the surface. In depth the conglomerates may be cut by the diabase, and if so there would be a chance for ore bodies in them and likewise for the occurrence of pockets at some distance from the intrusive rock.

On the surface shales probably come between the conglomerate strata and the diabase, as they do in the vicinity of the Esterly mine, though the hill slope above Spring Creek on the south, and next to the conglomerate outcrops farther north, is hidden by an unbroken mantle of soil and diabase fragments. In the fields above the wagon road, however, the position of the diabase wall may be closely estimated from the presence of a sharp rise in the profile of the hill, and the contact could be reached almost anywhere by short tunnels.

In view of the fact that only limestone beds have thus far been found to yield really important ore deposits of the Cornwall type, it can not be urged that this contact is a particularly favorable place for prospecting, though it is undoubtedly the most likely place for ore occurrence in the neighborhood. No general recommendation that the diabase contacts should be prospected through their entire length seems warranted, though the discovery of ore at any locality would naturally lead to a rather careful search at other points.

Both arms of the two horseshoe dikes closely approach and probably actually reach the northern edge of the Mesozoic area, and inasmuch as limestone occurs everywhere north of the boundary it would seem that ore bodies might be expected at the localities where the diabase and limestone come together. It is believed, however, that the diabase does not intrude the limestone at any of these places, but instead that the Paleozoic and Mesozoic rocks come together along a fault which has developed since the younger strata in the synclinal fold were invaded by the two sills of diabase.

BOYERTOWN DEPOSITS.

GENERAL DESCRIPTION.

The mining operations which have been carried on at Boyertown have developed the existence of five apparently separate bodies of magnetic iron ore, all of which exhibit the form of somewhat irregular layers of varying thickness. These ore layers seem to follow rather closely the stratification of a set of limestones and limy shales which constitute a transition between " No. I " sandstone and " No. II " limestone of the Paleozoic section, as given in the publications of the Second Geological Survey of Pennsylvania. In stratigraphic position these beds correspond with the ore-bearing strata at the Wheatfield and Fritz Island mines.

The mine openings are situated near the northwest edge of the Mesozoic belt, and the workings have shown that the three best-developed ore bodies lie immediately beneath a Mesozoic basal conglomerate composed of limestone fragments up to an inch in diameter set in a paste of red clay. This conglomerate bed, with a general southwest-northeast strike, dips toward the southeast, and beneath it the Paleozoic strata are so tilted that they lie in nearly parallel position. The two other ore bodies occur well within the limy beds of the Paleozoic at contact of a mass of intrusive diabase (Pl. VIII). The ore bodies just beneath the conglomerate are here called the East vein, the Hagy (sometimes known as the Eckert) vein, and the Warwick or Black vein. The deposits in contact with the diabase are known as the Rhoades and Blue veins. The East vein was worked from two inclined shafts situated southeast of Walnut street and known as Phoenix upper and middle slopes. The Hagy vein, outcropping south of the Reading road in the outskirts of town, was first worked by means of an open excavation known as the Hagy pit, afterwards by the so-called Eckert slope, and finally by the lower Phoenix or California slope. The Warwick vein has been worked both from the Warwick shaft and from the two shafts of the Gabel mine. In the latter mine it was called the Black vein. A body of ore ecountered in the lower workings of the California mine and known as ore No. 2 is believed by the writer to represent the northward extension of the Warwick vein. The Blue vein has been found only in the Gabel mine. The Rhoades vein has been opened from the surface at several places and also by means of two tunnels from the California slope.

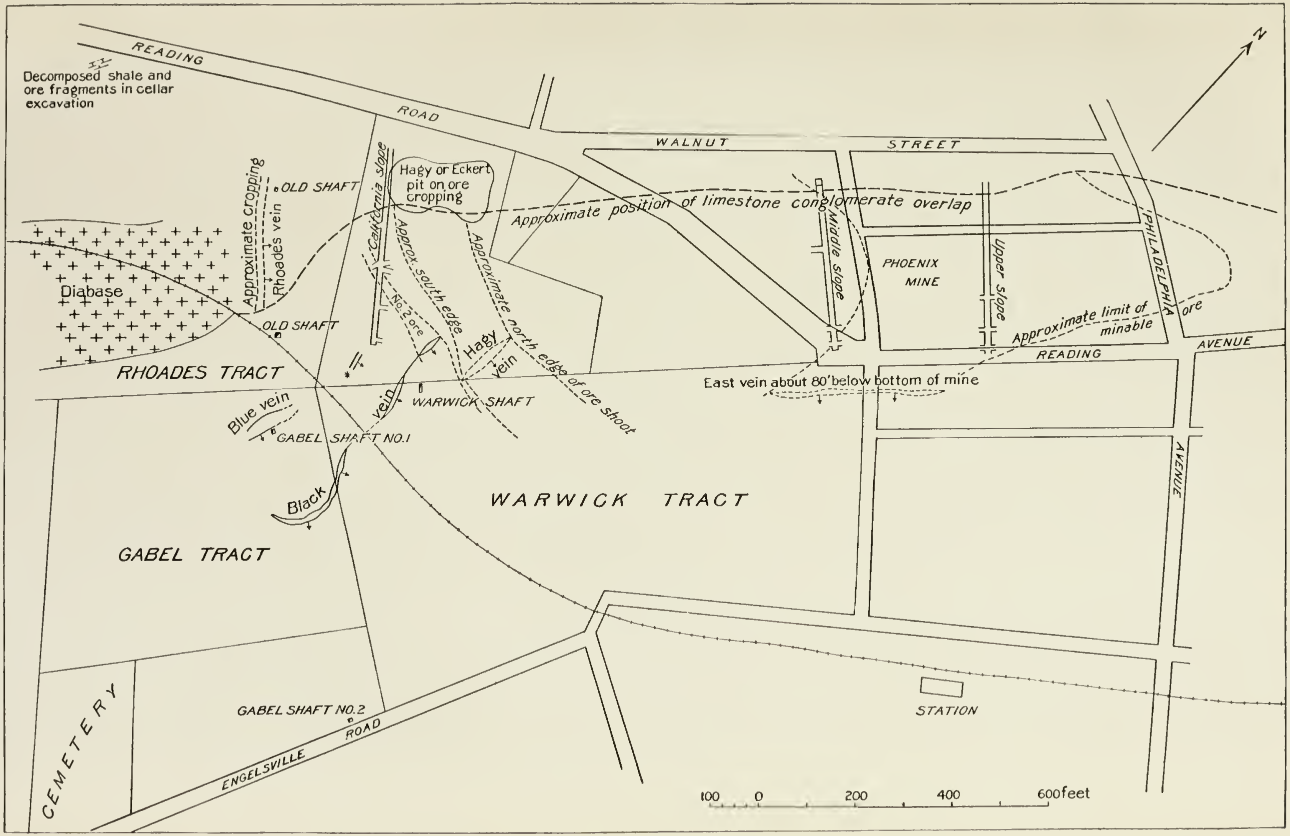
It is suspected that connection may eventually be established between the Blue and Rhoades veins, also that the Warwick and Hagy veins are parts of a once continuous ore body separated by a fault. These points and the possible relation between the East vein and the Hagy vein are discussed on pages 58–60. The relative positions of the several mines are indicated on the map (Pl. VIII).

The strata which carry the deposits occur in a narrow strip lying between the region of gneisses and sandstones northwest of Boyertown and the Mesozoic area on the southeast. The length of this strip is at least 2 miles and possibly somewhat more, but all the known ore bodies occur within a distance of less than half a mile.

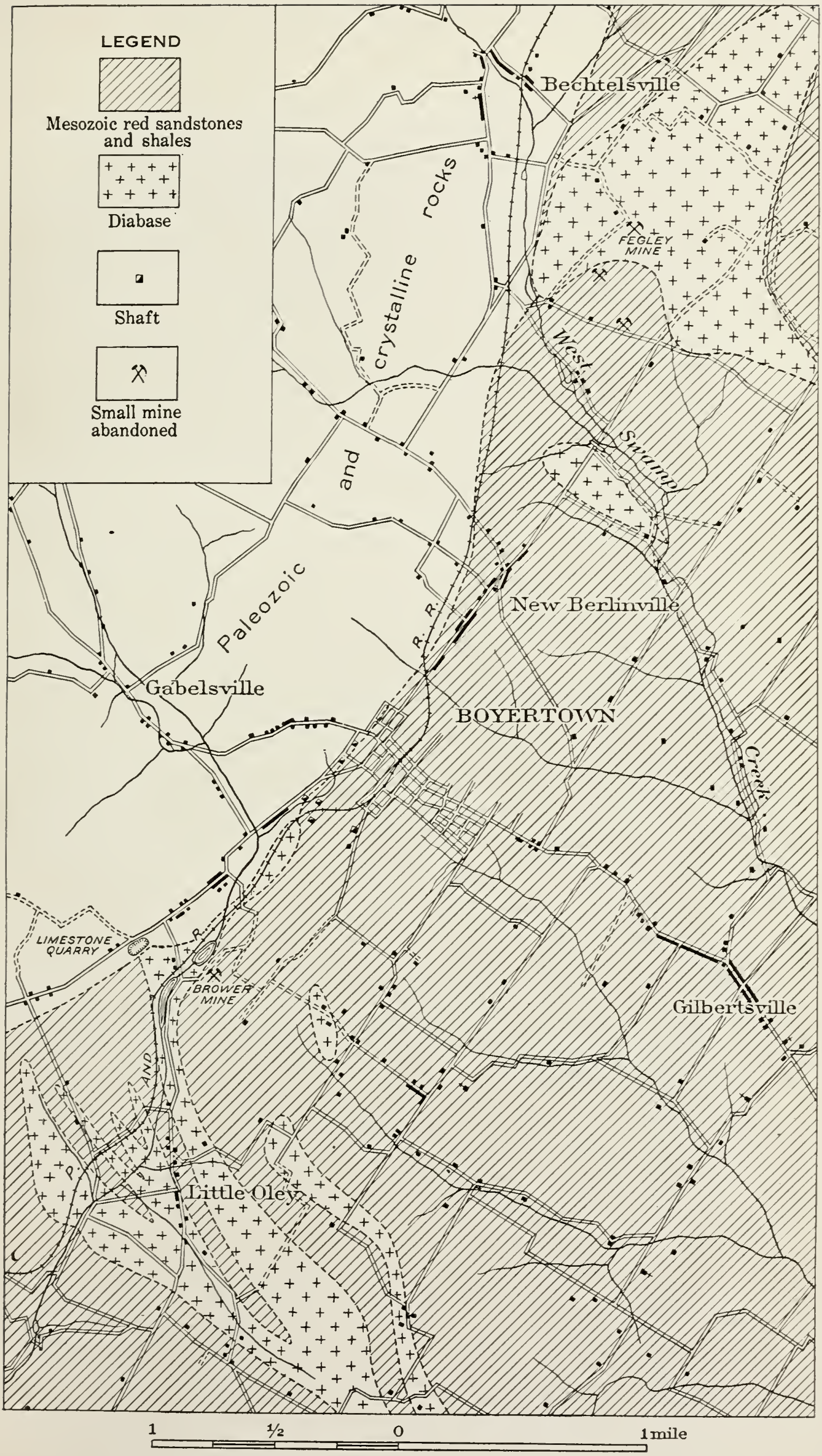
The situation of the deposits with respect to the Mesozoic rocks is similar to that of the Cornwall, Wheatfield, and Fritz Island deposits. Like all of these, they are associated with intrusive diabase, and though this association is somewhat less obvious at Boyertown than elsewhere it is sufficiently evident to justify the conclusion that the ores have been formed under the influence of the invading rock, as at Cornwall and other localities where ores of a similar type occur.

GEOLOGY OF THE DISTRICT.

Boyertown is situated near the northwest end of a roughly oval valley, 9 miles long from southeast to northwest, and about 5 miles wide. Ridges formed either by diabase sills or by sandstones and shales baked and hardened by the intrusive rock define this valley on three sides, the remaining or northwest side being formed by the Reading Hills, which are composed mainly of ancient gneisses, but contain also limestones and quartzites. From the ridges the strata dip toward the interior of the valley, which is thus structurally, as well as topographically, a broad basin. It is one link in a chain of four similar basins that extend nearly to Delaware River. Each of these basins is rimmed by diabase, the outcrops of which are nearly, if not actually, continuous. The great extent of the diabase, the continuity of its outcrop, and the persistency with which the intrusive rock follows the structure of the inclosing strata lead to the belief that it forms a practically unbroken sheet beneath all the basins that are surrounded by its outcrop. The basin here discussed is not com-



SURFACE MAP OF BOYERTOWN MINES, SHOWING RELATIVE POSITION OF ORE BODIES ON LEVEL SURFACE 400 FEET BELOW TOP OF GABEL NO. 1 SHAFT.



GEOLOGIC SKETCH MAP OF VICINITY OF BOYERTOWN, BERKS COUNTY, PA.

pletely rimmed by the igneous rock, but it seems probable that the two existing gaps, one near Boyertown and the other 3 miles to the northeast (Pl. IX and fig. 10), are to be explained on the supposition that in these places the invading rock was not able to force its way far enough upward to reach the present surface of the land.

Just south of the mines the western slope of Gabel Hill is formed by diabase, which marks the northward termination of a curving mass of intrusive rock that follows the base of the ridge and the valley of Ironstone Creek to Colebrookdale station and farther south connects with the rim-rock sills on the southwest side of the synclinal basin described above. The sedimentary rocks adjacent to this diabase have been greatly metamorphosed, and Gabel Hill, together with the ridge running southward from it, has been preserved from erosion by the indurated nature of the shales and sandstones of which they are composed. The originally red sandstones have been bleached to a dull white or yellow. A few outcrops suffice to show that the strata strike parallel with the course of the sill and with the crest of the ridge and dip to the east and southeast toward the interior of the basin. North and east of the blunt end of the diabase outcrop a few exposures of sandstone have the natural red color of the Mesozoic strata and show no induration. In the Warwick mine, however, and in both shafts of the Gabel mine limestone conglomerate lying above the black ore is somewhat metamorphosed, garnet and hematite being developed in it. These minerals occur also in bowlders both of limestone and siliceous conglomerate on Gabel Hill. The surface distribution of the metamorphic effects conforms so closely with the extent of the diabase that the presence of common metamorphic minerals in the conglomerate that occurs in the mines points definitely to the presence of intrusive rock near by. To judge, however, from the descriptions of D'Invilliers[a] and Willis[b] the instrusive rock is absent from most parts of the mines. Small dikes were noted in the Warwick mine and diabase is known to lie beneath the Rhoades vein and in the Gabel No. 1 workings beneath the Blue vein. Willis shows this rock as the foot wall of both the last-named veins, and indicates its presence in the crosscut tunnel from the 496-foot level of the Warwick mine, which was opened in search of the Blue vein. It is thought probable that a rather direct underground connection may exist between the Gabel Hill deposits near Boyertown and the masses of the same rock occurring northeast of New Berlinville, and also between the latter and the diabase that outcrops east of Sassamansville.

From scattered exposures strata corresponding with those which carry the ore layers are known to extend about one-half mile south-

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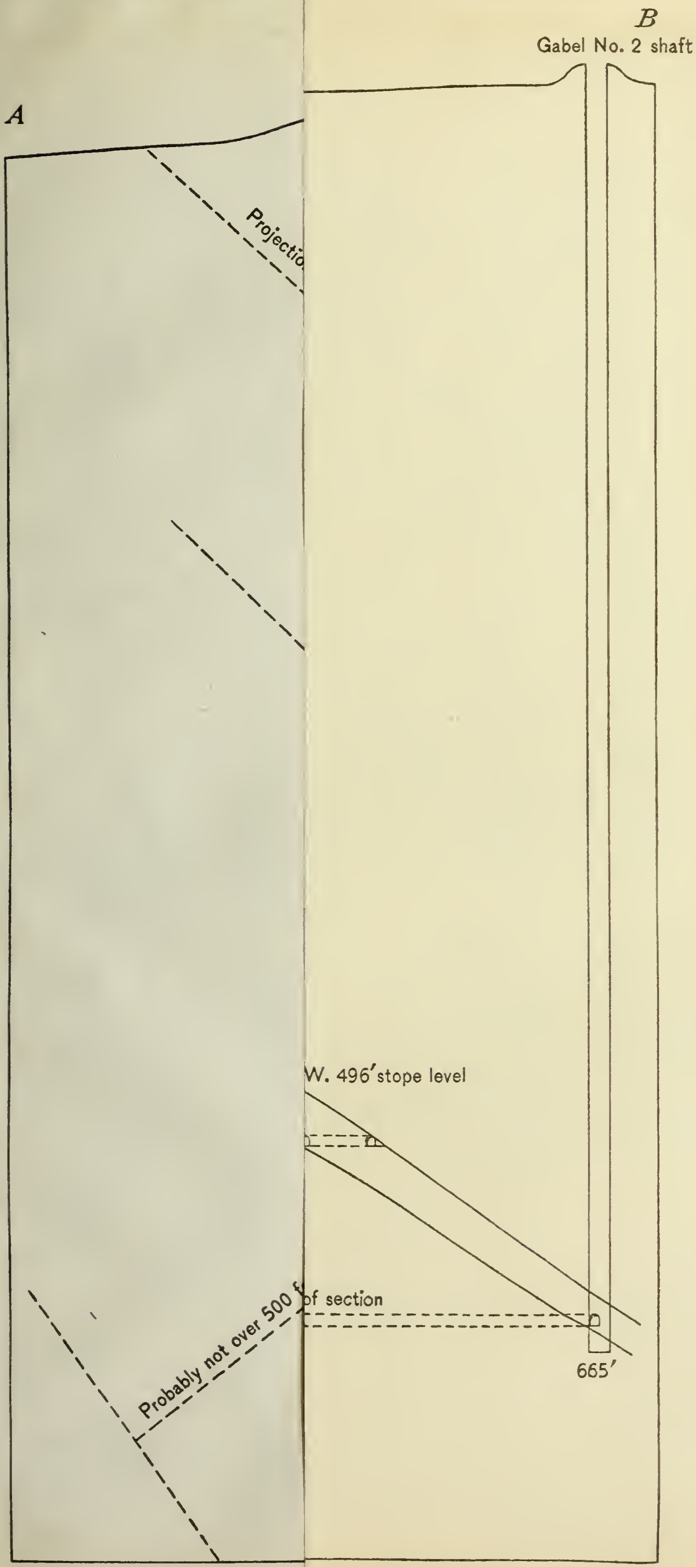
[a] Second Geol. Survey Pennsylvania, Rept. D3, vol. 2, pt. 1, 1883.

[b] Tenth Census, vol. 15, 1886.

west and 1 mile northeast of the mines, and they may continue considerably farther north beyond New Berlinville, beneath the alluvial wash of the swampy lands along the railroad. Shales including a dark carbonaceous layer have been revealed by an old pit in a field between the Reading turnpike and the railroad about half a mile north of the California slope, and shales broken down by surface weathering are exposed on both sides of the same road just where the trolley track leaves it and turns up the valley of Ironstone Creek. Decomposed shale was revealed in excavations for cellars made in 1906 on the south side of the road between the exposures last mentioned and the engine house at the California mine, and a few lumps of iron ore were found mixed with the clay. This material was apparently undisturbed, though it is possible that it may have been waste from the mines. A prospecting shaft situated between 500 and 600 feet northeast of Philadelphia avenue along the strike of the East vein showed the presence of carbonaceous shale which is reported to have been similar to some of the material associated with the ore, and which very likely represents the ore horizon, as the limestone conglomerate occurs near by. Fragments of similar limy and carbonaceous shale containing a little pyrite which came from a slope half a mile farther northeast, on the east side of the railroad track opposite the clay pit and brick kilns, may still be found scattered over the field. A hole was drilled near by, but no details of this prospecting have been obtained. The clay used in the brick works near New Berlinville station is weathered shale, and in places where the decomposition is not complete the rock closely resembles that which outcrops southwest of the California mine along the Reading turnpike. North of New Berlinville no exposure of shale has been noted, though it probably occurs west of the railroad between the track and the narrow band of quartzite that is represented on the geologic map of the Reading and Durham hills accompanying the Berks County report by D'Invilliers. From the mines northeastward to New Berlinville the shales and accompanying limy beds are overlapped by the Mesozoic strata, the strike of which, though variable from place to place, runs in general nearly parallel with the strip of Paleozoic rocks. The dip in both sets of rocks is toward the southeast and, as already noted, the strata lie nearly parallel. From the Rhoades mine toward the southwest the diabase sill appears to separate the strata of the ore-bearing group from those of the Mesozoic almost as far as the Gresh limestone quarry, a short distance east of which the sill turns southward into the Mesozoic area. At the quarry baked Mesozoic shales are seen almost in contact with the massive blue Paleozoic limestone. The hill above the quarry is covered with fragments of whitened and indurated sandstone.

S COUNTY, PA.

GENERAL PLAN OF WORKINGS AT BOYERTOWN MINES, BERKS COUNTY, PA.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Gabel No. 2 shaft
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W. 496′ stope level
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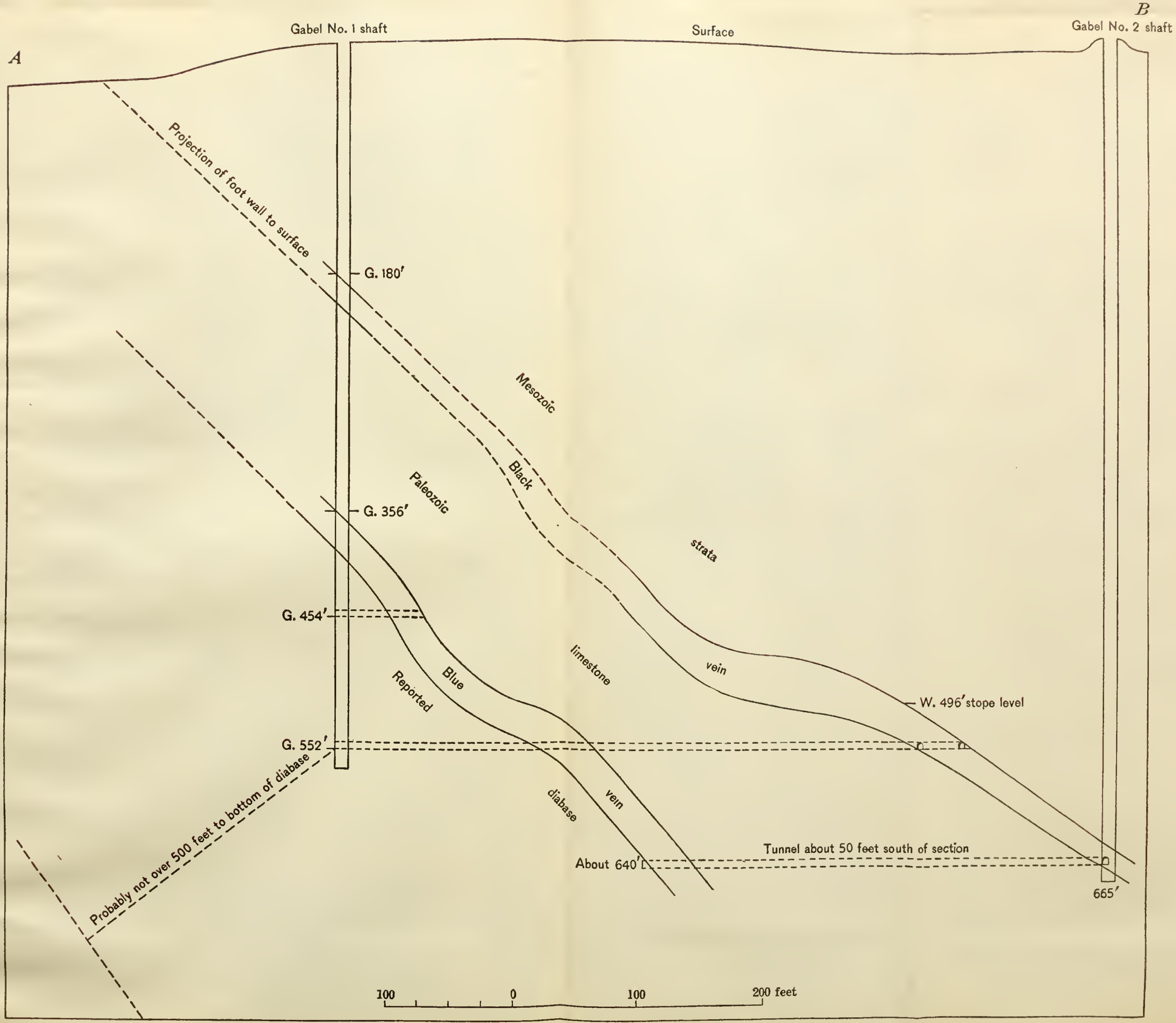

CROSS SECTION AT BOYERTOWN MINES (ALONG LINE A-B, PL. X).

THE WORKINGS.

All the mines of the Boyertown group were flooded when the writer visited the locality, and for this reason no first-hand information concerning the underground geology of the ore deposits enters into the present descriptions. The facts available in regard to the geology of the mines are those recorded by Willis and D'Invilliers, whose descriptions are quoted below. For the map of the workings which forms Pl. X acknowledgment is due the former engineer and superintendent of the Phoenix mines, Mr. J. H. Harden, of Phoenixville, by whom it was in part drawn from original surveys and in part compiled from data furnished by the several companies which formerly owned the mines. The workings of the 640-foot level of Gabel shaft No. 2 have been added to Mr. Harden's map from notes of a survey in possession of W. H. Dechant, successor to the practice of Kendall Brothers, civil engineers, formerly located at Reading. The cross sections of the mines (Pls. XI–XV) have been constructed from the data afforded by the mine maps, with the aid of sketches made by Mr. Harden. Their purpose is to show the general attitude of the veins, and they do not take account of the many existing irregularities of thickness.

DESCRIPTIONS BY WILLIS.[a]

The Phoenix mines present the simplest structure. Two inclines, having an average slope of 46°, are sunk on the ore, between a hanging wall of Mesozoic red sandstone and a foot wall of dark-gray limestone. Drifts * * * have been driven off on either side of the incline and the ore removed by stoping. The bed varies from 7 to 12 feet in thickness, and near the hanging wall there is usually a selvage of chloritic slate, which comes down in mining. The strike is quite regular, about northeast and southwest, and the beds have the apparent prospect of continuing indefinitely in either direction; just southwest of the lower incline the bed is pinched out, however, and no exploration has been made to ascertain whether it continues or not.

A shaft, known as Eckert's, * * * was sunk a short distance northeast of the California incline, and "Eckert's vein" was opened by it. The Phoenix company owns part of the mineral right on this "vein," and the California incline was sunk through rock to develop it and "Rhoades's vein," which was known by surface workings.

* * * The northeast drifts of the California mine reach the southwest end of Eckert's ore, while two long crosscuts have been driven through limestone to Rhoades's deposits. Eckert's is like the Phoenix in geological relations, but strikes nearly north and south, with a dip to the east.

Rhoades's vein strikes at right angles to the Phoenix, southeast and northwest, and dips northeast; it has a hanging wall of limestone and foot wall of trap, and in this resembles the deposit opened by the Gabel shaft [Blue vein]; the ores obtained from the two openings are also very similar, and the differences of strike and dip are hardly sufficient in so disturbed a corner to render it improbable that they belong to the same deposit.

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[a] Tenth Census, vol. 15, 1886, pp. 229–231.

The lowest working in the California mine, on Eckert's vein, is 218 feet from the surface at the top of the incline; the dip is about 45° toward the east. This drift is 240 feet from the Warwick shaft, measured on the map. Ore was first struck in that shaft at a depth of about 400 feet, probably 425 feet below the top of the California incline.

A dip of 38° to 40° would place a southern extension of Eckert's vein in the position of the ore cut in the Warwick shaft. It does not follow that the ore body is continuous from the Warwick workings up to the California drifts. In fact, the trap which lies west of the Warwick shaft and that penetrated in the long crosscut toward the Gabel mine render it very improbable that there is an undisturbed body of ore here; but it does seem probable that the Warwick, the Eckert, and perhaps the Phoenix beds, which all have a red-sandstone hanging wall and a limestone foot wall, are disturbed portions of the same originally connected bed.

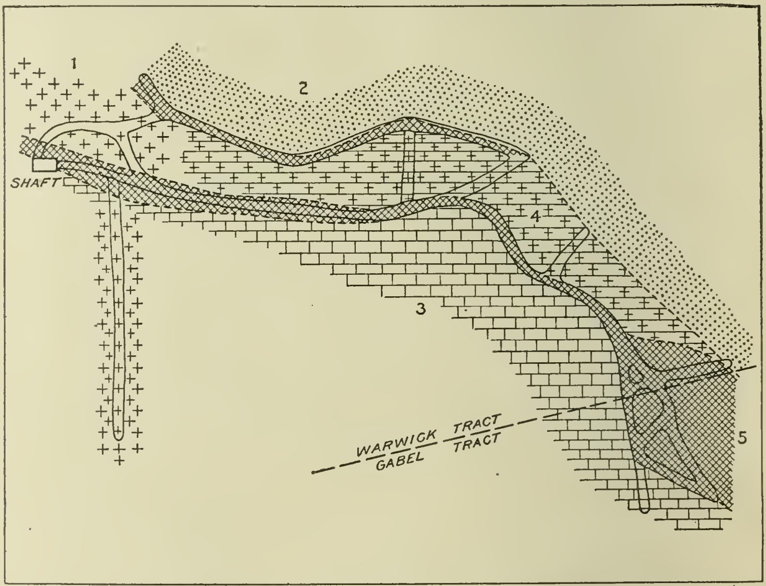
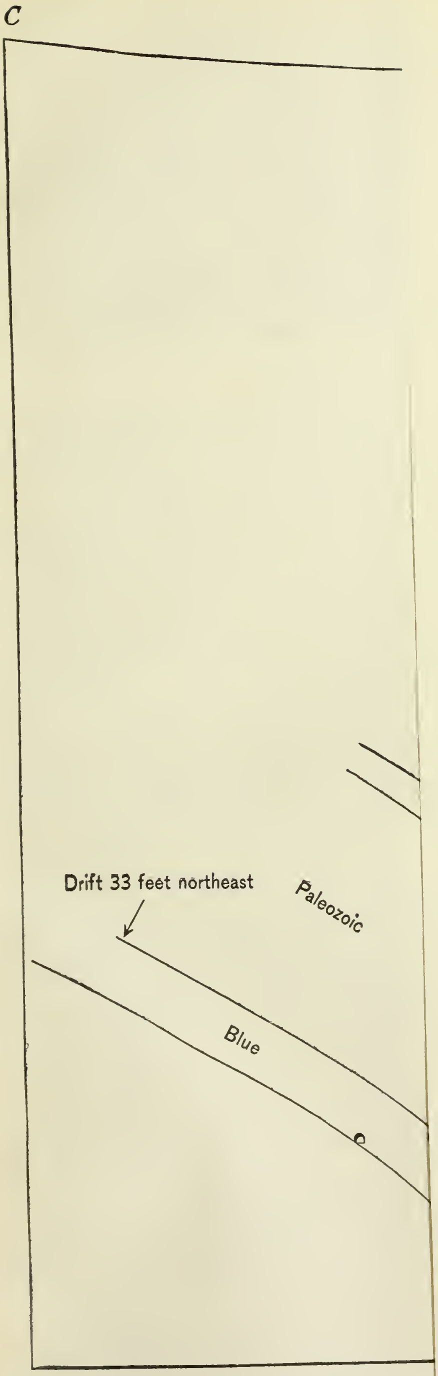


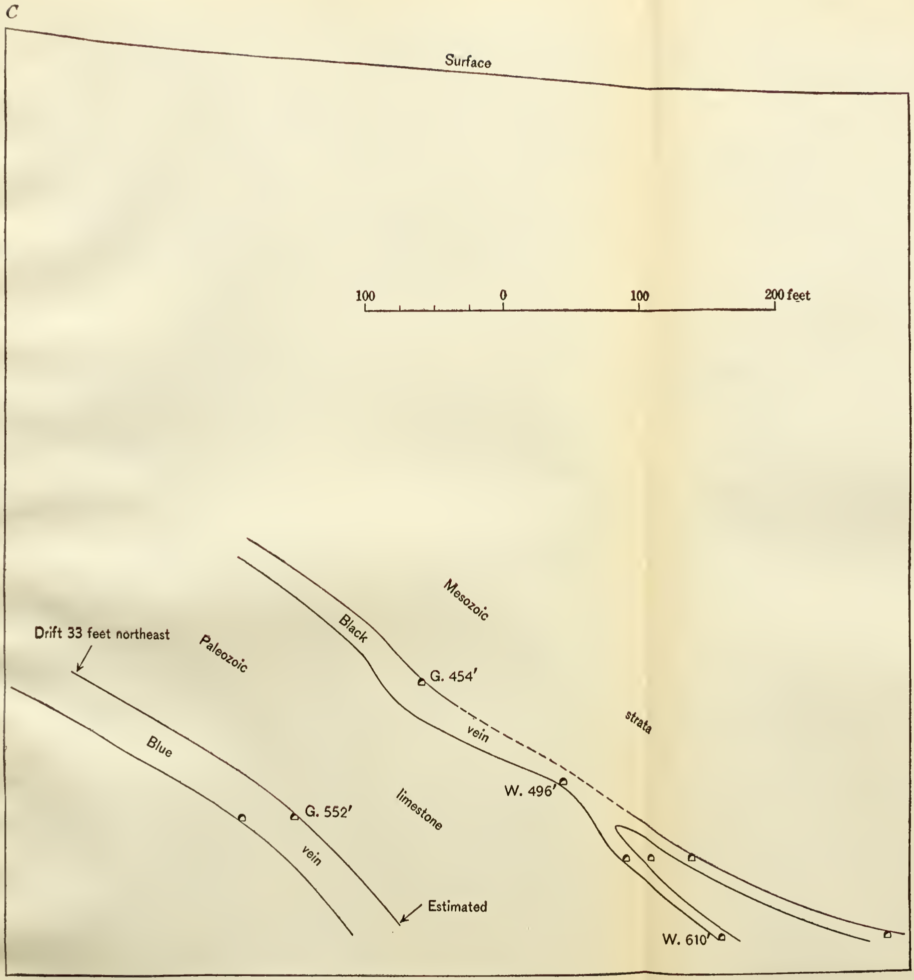
FIG. 6. Plan of upper or 496-foot level, Warwick mine, after Willis. 1, Diabase; 2, Mesozoic sandstone; 3, limestone; 4, limestone mixed with ore; 5, magnetite ore.

A special map is herewith given of the Warwick mine [fig. 6]. It is opened in the most disturbed portion of the belt, and the apparent development of two parallel ore beds, together with the exceptional facilities afforded by the kindness of Captain Polkinhorn, led to careful study of it. In the long drift on the middle level, toward the south, there is a well-defined limestone foot wall. The hanging wall of red sandstone is also uninterrupted; but between the two, and especially in the northern end of the mine, the limits of the ore are very ill defined. The wall is usually mixed limestone and ore, and mining is left off simply when the proportion of ore to limestone becomes too small to pay.

Where the ore body turns southward the upper bed of ore approaches the lower bed, and it will probably be found that there is but one extending southeastward beyond the next turn in the Gabel property. The variations in the thickness of the ore bed and the positions of the associated limestone, red sandstone, and trap are given in the accompanying special map.



CROSS SECTIC



CROSS SECTION AT BOYERTOWN MINES (ALONG LINE C-D, PL. X).

Accepting the inference that the Warwick, Eckert, and Phoenix deposits have originally formed parts of one bed, though now disturbed and separated by "pinches," it is difficult to understand how the Blue (Gabel) vein and the Rhoades vein can ever have been part of that bed.

The foot wall of the Phoenix and the Eckert mines is apparently tilted, but otherwise a little-disturbed and continuous stratum. Away from the trap, which has confused the deposit near the Warwick shaft, the limestone foot wall is in that mine also well defined. The long cut driven from the Gabel bed to the large deposit in the south end of the Warwick mine passes through 175 feet of limestone. The same material lies uninterruptedly between the Eckert and the Rhoades beds. Hence it seems highly probable that there are here two distinct deposits of ore. With this in view, it would be interesting to know the results of exploration north of the Phoenix mines.

DESCRIPTIONS BY D'INVILLIERS.

The following descriptions of the several mines are abridged from D'Invilliers's account of the Boyertown mines:

Phoenix upper and middle slopes.[a]—These slopes are 350 feet apart and both work the same body of ore, averaging from 12 to 15 feet in thickness, though at many places swelling into bunches three times as large in different portions of the different gangways. The dip of the ore averages about 45° SE. The upper slope is 353 feet deep, vertical measurement, its top being located 6 feet higher than Gabel shaft No. 1. The lowest drift is driven on this slope from the bottom for about 150 feet each way northeast and southwest, but the courses have never been surveyed, and consequently could not be located. Forty-three feet vertically above this is the middle drift, likewise driven each side of the slope about 160 feet northeastward and 300 feet southwestward to the middle slope. The upper drift is 267 feet below the surface and 43 feet above the middle gangway, and has been driven each way about 300 feet, connecting on the southwest with the middle slope, as on the lower level.[b]

The top of the middle slope is at the same elevation as the upper one, and it is about 310 feet long, with two levels corresponding and connecting with the upper and middle levels on the upper slope. The middle slope was driven in rock, but the upper slope was driven on ore all the way, and as the ore body here is much softer than in the middle slope a great deal of trouble and expense has been necessary to keep the slope in repair. This has led to its proposed abandonment and to the erection of permanent buildings at the middle slope, from which all future mining will probably be carried on. These improvements were hardly consummated when the dull times of 1880 and

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[a] D'Invilliers, E. V., Geology of Berks County: Second Geol. Survey Pennsylvania, Rept. D3, 1883, pp. 314–316.

[b] This level was afterward extended to a distance of about 500 feet northeast of the slope and reached beyond Philadelphia avenue, according to the statemnet of Richard Richards, former foreman of the Phoenix company.

1881 led to the closing of all the mines, and the two upper slopes are still filled with water [1883]. It is likewise proposed here to further test the property by driving northward from the slope to prove the presence or absence of the underlying blue ore bed.[a]

The true foot wall in both these slopes is an altered syenite carrying thin seams of earthy magnetite with dull luster, in many places massed or bunched, and showing but little crystallization.[b] The syenite is filled with pink feldspar nodules, hornblende, and epidote, all distinctly stratified. In the upper slope, however, a dark greenish-black unctuous limestone layer is found at many points between the main body of the ore and the true foot wall, much of it carrying chert in large masses. The top wall is a decomposed, light greenish-gray, serpentine limestone, slaty and carrying crystals of pyrite. The ore rock is generally an impure conglomerate limestone carrying masses of dull-colored crystalline limestone, serpentine, and magnetic ore, but the bulk of it is a green to black dolomite with coatings of calcite. The ordinary run of the mine shows a mixture of magnetic iron ore, with limestone and minute crystals of iron pyrites diffused through the mass. Locally the pyrite occurs in large and well-defined crystals.

Phoenix lower slope, or California mine.[c]—The developments here consist [1883] of a slope about 300 feet long, from which three levels have been driven toward the northeast for the purpose of working the Hagy ore bed, and two toward the southwest to meet the Rhoades vein. The lowest level was driven first for about 50 feet through a dark quartzose sandy rock of a bluish color. The course of the gangway being thought to be turned too much toward the east to strike the ore, the next 50 feet was driven more to the north, likewise through rock, until at a distance of 110 feet from the foot of the slope ore was struck. The original northeast course was resumed and carried through ore for 50 feet more. The gangway at the time of visit showed a chamber fully 22 feet wide, without showing foot or hanging walls. The dip of this western body of black ore is probably toward the southeast at a steep inclination.

The middle drift is about 40 feet vertically above the lowest, and in driving northward from the shaft the same characteristics were met as already noted in the lower level. The drift is not parallel to the lower level, but turns somewhat more toward the northeast. For the first 30 feet it passed through rock, beyond which the ore body was met in a rather pinched condition.

The upper level is driven northward from the slope about 176 feet vertically below the surface of the ground. It extends for about 80

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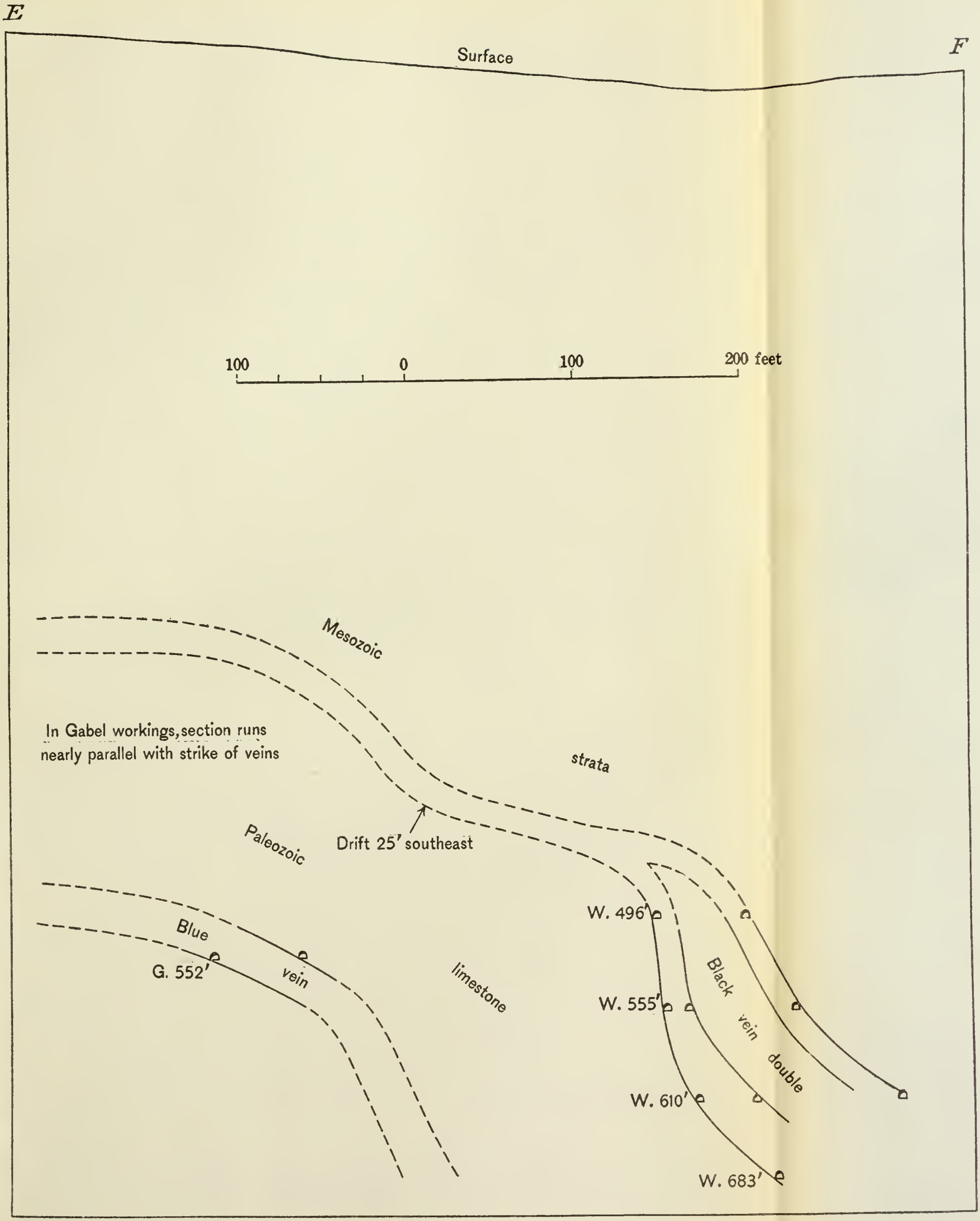
[a] Mr. Richards states that this exploration was made, but that no ore was found.

[b] Compare with statement of Willis, p. 49.

[c] D'Invilliers, E. V., op. cit., pp. 308–311.



CROSS SECTION AT BOYERTOWN MINES (ALONG LINE E-F, PL. X).

feet along the south line of the old Eckert open cut, and the ore body pinches toward the northeast.

Exploration has been carried on south of the slope, where the workings consist of a rock tunnel driven southwestward for about 200 feet at a depth of about 176 feet through a mixed micaceous and quartzose rock to the Rhoades vein, which strikes about S. 25° E. and dips a little east of north at an angle of 50°. A similar rock tunnel was driven from the middle level in a nearly parallel direction, and from its extremity a raise has been opened to strike the vein on the upper level. A fine face of ore 30 feet thick is exposed in this middle level, but, owing to its inferior quality as compared with the Hagy ore, work has been suspended [1883]. The thickness of this bed varies greatly, as is the case throughout all the mines. The gangue is similar to that of the Hagy mine, being mostly silica, lime, and magnesia, but the ore is leaner in iron and carries more sulphur and a little copper, being identical in composition and physical attributes with the blue ore of the Gabel mine. In the Gabel mine the Blue vein is separated from the overlying Black vein by 150 feet, more or less,[a] of impure limestone, but the Hagy and Rhoades veins are divided by a rock which is apparently a rotten quartzose gneiss, though the gangue of the ore itself in each place is largely limestone.[b]

Warwick mine.[c]—The Warwick mine has three levels [1883], with numerous gangways and counter gangways, many of which have been long since abandoned and could not be explored. The first level is 420 feet vertically below the surface, the second 500 feet, and the third 567 feet [corresponding with 416-foot, 496-foot, and 555-foot levels as given on Pl. X]. Two gangways were driven on the 500-foot level, one on the hanging wall, which is generally Mesozoic, the other extending toward the southeast and thence south into the Gabel property and showing generally a limestonce foot wall. The average horizontal distance between these gangways is about 50 feet, which would give a thickness of about 25 feet of ore, measured at right angles to the dip. The space between, however, is by no means entirely occupied by ore, but contains numerous horses of serpentine, limestone, and greenstone, as well as many occurrences of pinching where the foot and hanging walls come together. Pinching is particularly noteworthy in the north gangway, where about 150 feet from the shaft the ore is only from 3 inches to 1 foot, and again at the end of the gangway, where the ore is entirely cut off.

The ore is found everywhere to lie in lenticular-shaped bodies, thinning out in the line of strike and swelling to immense bunches in

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[a] One hundred and sixty feet, as measured on the map.

[b] To judge from the workings on the 176-foot level of the California mine, the horizontal distance between the Hagy vein and the Rhoades vein is about 175 feet, but the two veins strike in very different directions—in fact, at an angle to each other of about 45°.—A. C. S.

[c] D'Invilliers, E. V., op. cit., pp. 320–324.

the center, variously mixed with limestone, with which it seems to be here and there intimately interstratified. A fine illustration of this relation was furnished in the lower [454-foot] level of the Gabel mine, where in a piece of limestone 6 inches thick there were four bands of interstratified ore from ½ to 1 inch thick.

From the 500-foot level to a point 90 feet out from the shaft a crosscut was driven S. 40° W. in search of the Blue vein found in the Gabel mine. It is probable that this bed exists in the extreme southwest corner of the Warwick tract, but, except at lower levels, it would not pay to stope it, as it must within a short distance pass into the adjacent properties.

The crosscut was not driven far enough to reach the Blue bed, for the slight development of this vein in the Gabel mine shows that it has a decided tendency to bear toward the northwest, in the direction of the lower Phoenix slope. The crosscut was closed at the time the mine was examined, but it was said to have been carried first through 10 feet of limestone, then 4 feet of ore, and for 143 feet through quartzose sandstone.[a]

From a point beneath the railroad to the boundary with the Gabel property the south gangway on the 500-foot level is driven through limestone and ore, the former being the general foot wall and dipping about 35° SE. A great deal of ore has been obtained from stopings carried up from this gangway along the foot wall. Masses of calcite, bearing clusters of pyrite, are seen in numerous places accompanying the ore.

Close to the property line the north edge of an immense body of ore appeared, and in parting the drift to work it the ore was found to be fully 40 feet thick. The absence of connected surveys led to the continuation of both drifts into the Gabel property, from which fully 8,000 tons of ore was eventually extracted. A magnificent pillar of excellent black ore still remains as the support to the roof of this immense chamber. A crosscut from the foot to the hanging wall was in ore for its entire length.

Inspection of the lowest 567-foot level in this mine [555-foot level of Pl. X] will show that two gangways have been opened, connected in two places by crosscuts.

In the two parallel gangways driven eastward from the shaft to meet the ore body a considerable mass of limestone was driven through, extending as far as 125 feet from the shaft, after which ore was encountered to the Mesozoic conglomerate hanging wall, dipping here 50° to 55° a little south of east. The last 60 feet of the southern of these two drifts was entirely in ore, which here spreads out to a pinch within about 30 feet to the northeast along the main gangway, branching off from the north crosscut. The quality of the ore here

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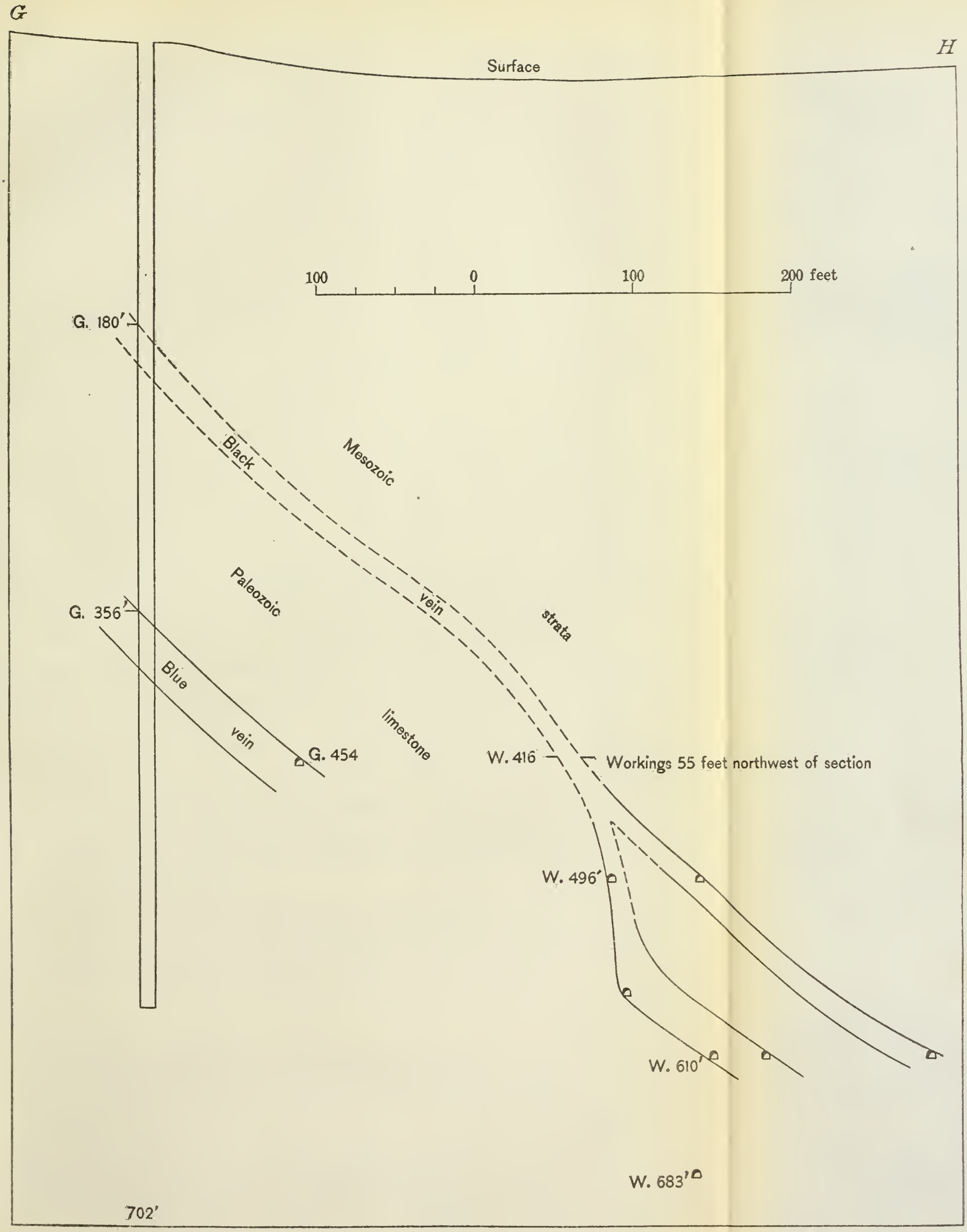
[a] The rocks through which this tunnel was run are shown by Willis as diabase.



CROSS SECTION AT BOYERTOWN MINES (ALONG LINE G-H, PL. X).

was excellent, but it was soon cut off by the meeting of the limestone and the Triassic measures [conglomerate]. To the south-southeast, along the hanging-wall gangway, the ore gradually thins away, and about 60 feet below the south crosscut it ranges from 3 inches to 1 foot. This pinch corresponds closely in position and character to that already mentioned as occurring on the 500-foot level, and the gangways are essentially parallel. The pinch on the hanging-wall gangway extends for 50 feet, to a point where the gangway makes a decided turn toward the S. 40° E.; here another body of ore was encountered, 10 feet thick and swelling into the hanging wall, but pinching again in about 35 feet. This ore was stoped up for about 40 feet, where it was found to extend back over the pinch, thus showing the presence of bulging and thinning on the line of dip. The S. 40° E. course extends for 120 feet to a point under the railroad, where the gangway turns southward and shows a limestone top. Sixty feet beyond, a greenstone dike was encountered similar to that occurring in several places in this and in the 500-foot level along a line from this point to the shaft. These dikes are nowhere of great thickness, and generally dip to the northeast. Where diabase is present it usually forms a true foot wall, no ore being found beyond it, but in the 567-foot level in the hanging-wall gangway it partakes more of the character of a horse, having ore on both sides.

The foot-wall gangway on this level is almost entirely in ore, in many places with a very steep dip and in one place even overturned. Inspection of the mine map will show that the foot-wall gangway of the 567-foot level lies very nearly underneath the foot-wall gangway on the level above. On both levels the gangways have a general curve convex toward the east, and toward the south the dips become lower and lower until near the Gabel property line they do not average over 35° and here and there fall to 20°. Because of the low dip in the southern part of the mine most of the stoping has been confined to the 500-foot level.

A little development has been made on the 420-foot level, but here the dip of the vein carries the ore beyond the property limits within a short distance, so that no extensive work has been done.

Gabel mine.[a]—A vertical section through the Gabel No. 1 shaft shows—

	Feet.
Banded shales, sandstones, and conglomerate, with a layer of altered mud rock about 5 feet thick at the bottom	180
Black bedded ore, folded and broken, and consisting mostly of calcareous breccia	26
Limestone	150
Blue ore bed (measured across the bedding 20 feet)	55
Chloritic rock or greenstone [probably diabase]	74

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[a] D'Invilliers, E. V., op. cit., pp. 328–330.

The mine has two levels, the upper 180 feet [160?] and the lower 474 feet [454]. Some development was carried on in the upper level close to the shaft, but the ore was greatly mixed with a light-green limestone gangue and in addition was greatly broken and folded. The underlying limestone was similar to that found in the Warwick mine, being mostly a serpentine-green limestone of a light color, but the gangue-rock limestone is much darker and in places black from the contained ore.

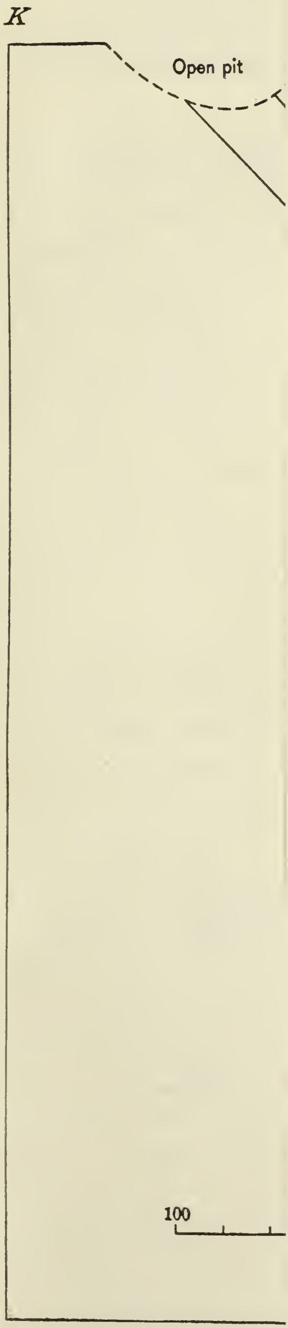
While mining in the upper level the Gabel Company became convinced of the trespass that had been made on its property through the 500-foot level of the Warwick mine. From the 474-foot level a main gangway was started toward the southeast, in which the blue bed was struck 30 feet from the shaft. This ore extended for 33 feet, the vein dipping about 60°. At the Blue vein the course of the gangway was turned somewhat to the left, and the remaining part of the gangway was entirely in limestone, at first dipping rather steeply but afterward flattening as the Black vein was approached. About 175 feet beyond the hanging wall of the Blue vein the foot wall of the Black vein was struck. The gangway came into the Warwick Company's stopes, which had been driven up from its 500-foot level on a dip of about 35°. In the Gabel shaft the two ore beds and the strata which lie between them all dip about 45° S. 55° E.

The ore beds in the Gabel mine are like those in the other shafts. They occur in masses and bunches 40 feet thick, which pinch out to mere leaders and are therefore by no means continuous bodies of ore. The ores, however, show one difference, in that they are harder and more compact than in the other mines, probably on account of their proximity to the Gabel Hill dike, which may have exerted some influence in altering their physical properties.

From the 474-foot level two gangways have been driven in the foot wall of the Black ore bed. Owing to its great thickness here and large limestone partings, stoping has been carried up almost to the shaft, where the Black vein was cut 180 feet below the surface, thus proving the identity of the brecciated bed there found with the magnificent body of ore in the lower part of the mine.

The Warwick gangways have likewise been extended along the hanging wall [" new red "—that is, limestone conglomerate], but not from the 500-foot level, being started from the stopings above. These drifts along the hanging wall, as well as those on the foot wall, have been carried a considerable distance to the south, two of them being at least as far out as the barn. These gangways exhibit the tendency of the ore body to swing around Gabel Hill.

Some stoping has been done on the Blue ore bed, but the inferior quality of this ore delays its extended development. The company intends [1883] to sink another lift in the near future, from which


K
Open pit
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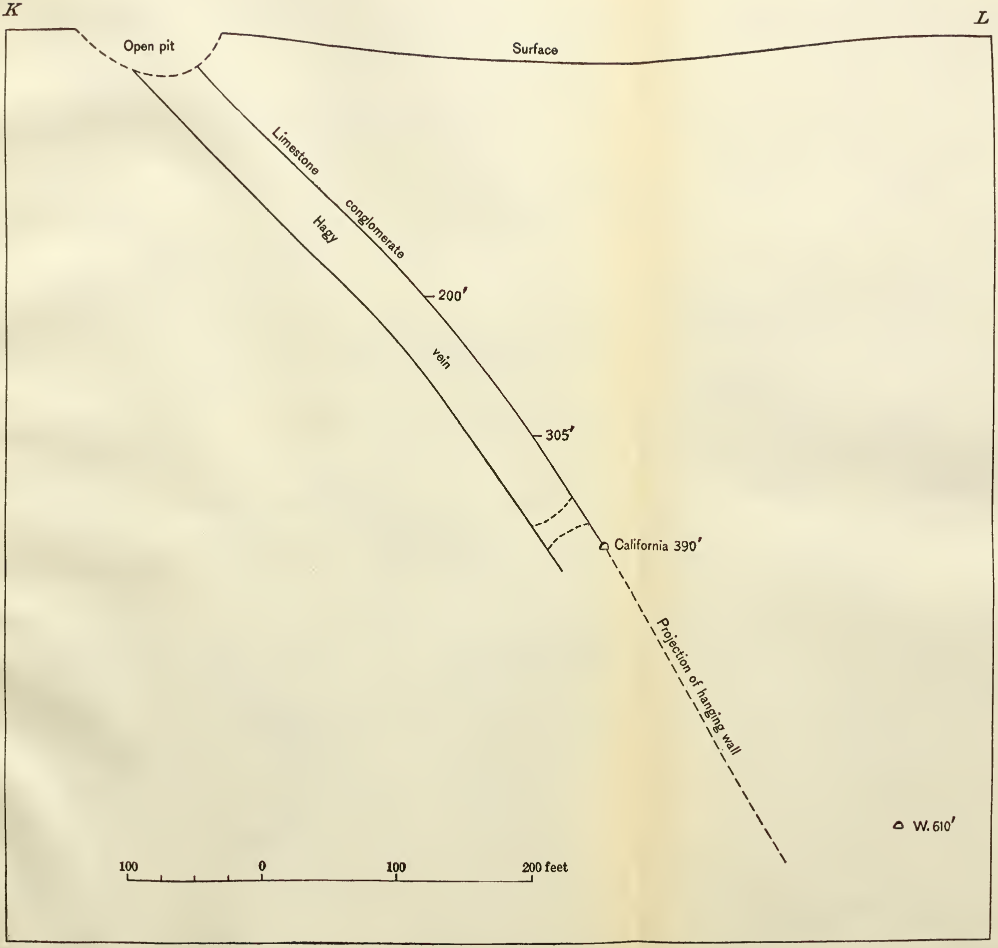


CROSS SECTION AT BOYERTOWN MINES (ALONG LINE K-L, PL. X).

it will drive to the southeast, thus opening a third level on this valuable ore tract. [See 552-foot level, Pl. X.]

A crosscut was driven from the 474-foot level toward the southwest into the hill, but the ore was found to be cut off in this direction by the diorite dike which outcrops on the north side of Gabel Hill.

LATER DEVELOPMENTS.

The descriptions which have been given include the tunnels and shafts opened before 1883. Between that year and 1893 the workings of the various mines were considerably extended. Gabel shaft No. 1 was carried to a depth of about 570 feet, and on the 552-foot level a crosscut was run to the Blue and Black veins, giving stoping ground of 98 feet vertically below the next level above. Gabel shaft No. 2 was sunk to a depth of 665 feet. The shaft encountered the Black vein at about 640 feet, but the thickness of the ore body can not be stated. The workings from the shaft comprise two short drifts in the ore body. The northerly drift, about 55 feet long, is connected by a raise with the 552-level of Gabel No. 1 mine. The southerly drift is 25 feet long and from its end a crosscut tunnel penetrates the foot wall. The length of this tunnel is about 360 feet. About 35 feet from its end short drifts, which extend to the right and left, are supposed to follow the hanging wall of the Blue vein. Unfortunately no person was found who had worked in this tunnel, and its depth below the surface is not accurately known. Between shaft No. 1 (where the ore was first cut at a depth of about 180 feet) and shaft No. 2 the Black vein had been proved as a continuous layer for about 800 feet in the direction of dip. On the trespass level the drifts in ore within the Gabel property were about 250 feet long, and from the Warwick shaft the vein had been followed for 400 feet before crossing the property line.

The Blue vein lies below the Black vein somewhat more than 100 feet, measured normal to the bedding, or from 160 feet to 325 feet measured along the various crosscuts. It has been mined on the dip to the height of about 375 feet and on the strike to a maximum length of about 250 feet. On the 640-foot level neither vein had been fully developed when mining was suspended. To judge from the course of the Blue vein in the higher workings, it is not likely to extend more than a short distance into the Warwick plot. All of shaft No. 1 below the Blue vein—that is, below a level about 400 feet from the top—is supposed to be in diabase (greenstone of D'Invilliers's description), though no positive statement to this effect was made either by Willis or by D'Invilliers.

No information has been procured in regard to the behavior of the ore bodies in the southernmost workings of Gabel No. 1 mine, but the fact that none of the drifts were extended for more than 200 feet from the crosscut may indicate that both veins come to an edge in this ground. In view of the uncertainty which exists on this point it would be safer to lay out any exploration for the veins at lower levels southeast of the shaft rather than south or southwest.

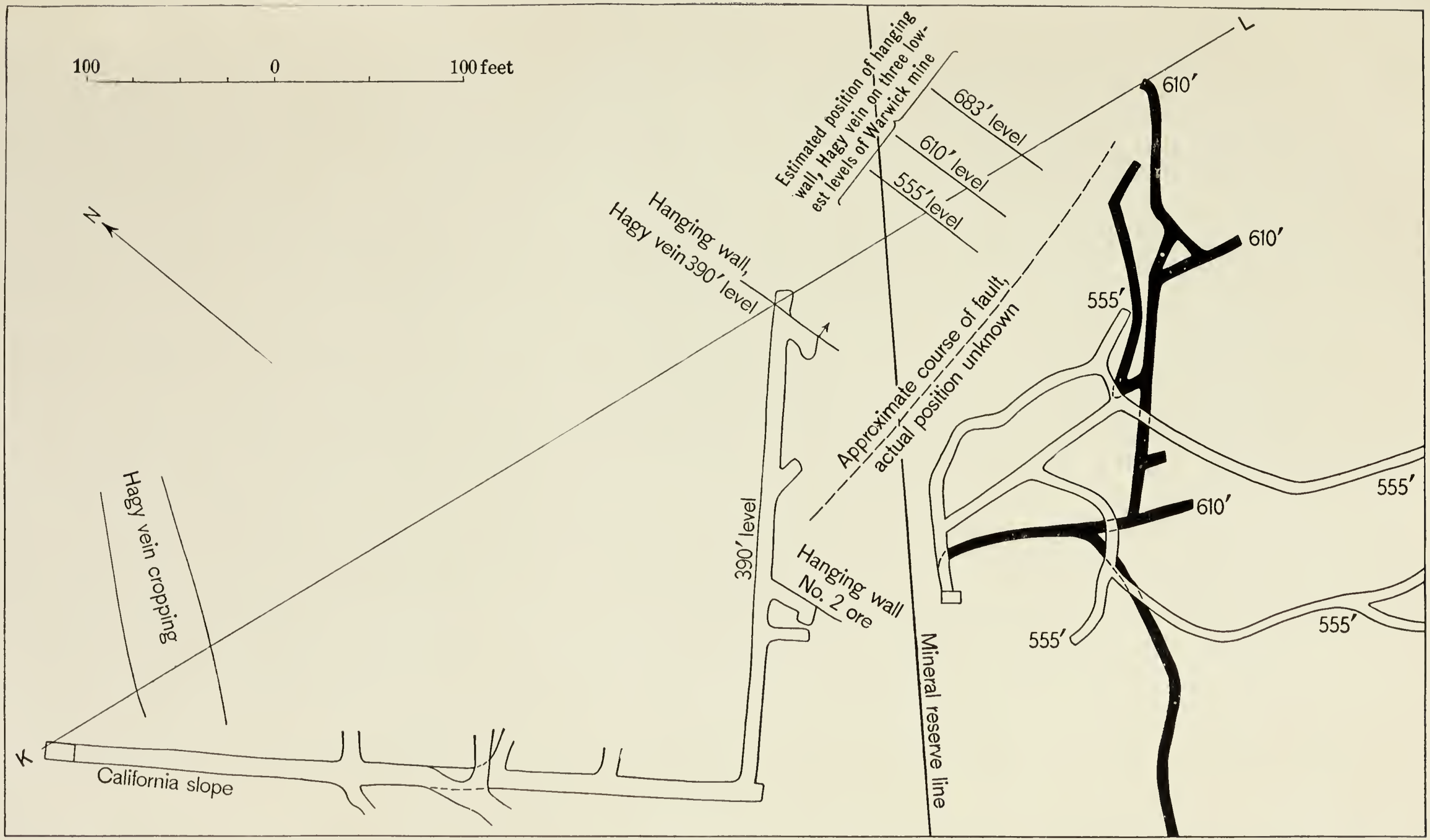
In the Warwick mine two lifts were sunk after 1883. On the 610-foot level the vein was found to be double (as on the 555-foot level), and both the foot-wall and hanging-wall leads were developed by drifts extending southward nearly to the property line.

An extension of about 120 feet would connect the foot-wall gangway with the 640-foot level of the Gabel mine. On the 610-foot level a crosscut 200 feet long which was run into the foot wall nearly to the property line failed to locate the Blue vein, but nothing is known concerning the rocks penetrated. Unless diabase was encountered it would seem to be worth while, in view of the present control of both the Gabel and Warwick tracts by the same company, to continue this tunnel to the diabase, for in the Gabel mine, at about the same elevation, the horizontal distance between the Black and Blue veins was about 325 feet. In the eastern drifts of Gabel No. 1 mine the manner in which the Blue vein curves toward the north and the fact that the drift on the 552-foot level if continued in its course would pass nearly under the end of the drift on the 454-foot level suggest that in this ground the Blue vein stands very steeply.

In a search for the Hagy vein two tunnels were run into the hanging wall on the 610-foot level about 100 feet east of the shaft. Though the vein was not located, it is probable that it may yet be discovered by extending the exploration toward the north or northwest. This point is referred to again on page 59.

The workings on the Warwick 683-foot level, so far as is shown on the map (Pl. X), comprise a gangway 200 feet long, apparently on the foot wall of the vein, and two crosscuts, one into the foot wall and the other started toward the hanging wall. No data have been procured concerning the ore body on this level, and the nature of the rock encountered in the lower part of the shaft is not known. It may be suggested that if the Warwick shaft penetrated any considerable mass of diabase there can be no further probability of encountering either the Blue vein or the Rhoades vein on the lowest level, as the foot wall of both is the Gabel Hill intrusive mass. On the other hand, if the main mass of diabase has not been encountered there is still a chance of finding ore by locating and exploring the diabase contact.

In the California mine the workings now reach a vertical depth of 390 feet, two levels having been opened below the 200-foot level, which was the lowest in 1883. Just beneath the old sump a body of ore was encountered which was known as ore No. 2. On the 305-foot level, where the same bed was struck about 20 feet from the



PLAN OF CALIFORNIA AND WARWICK MINES AT BOYERTOWN, PA., SHOWING POSITION OF FAULT.

slope, it extends for about 30 feet along the drift and is reported to be 18 to 20 feet thick. On this level about 45 feet beyond ore No. 2, or 95 feet distant from the slope, the Hagy vein was encountered. Along the hanging wall it was mined for 125 feet. On the 390-foot level ore No. 2 was cut about 75 feet from the slope and it continued in the drift for about 30 feet, with a maximum thickness of about 20 feet. Fifty feet farther on the Hagy vein appears and, being cut diagonally, continues for about 90 feet in the drift. This vein has been stoped from the 390-foot level to the bottom of the Hagy pit, or about 500 feet along the dip.

In the California mine the southernmost workings in the 390-foot level on ore No. 2 are about 60 feet distant from the Warwick shaft and about 30 feet higher than the 416-foot level of the latter mine on which the Warwick vein was first opened. The proximity of these workings leaves little doubt that ore No. 2 and the Warwick vein are parts of the same ore body, as has been commonly supposed by persons most familiar with these mines.

PRACTICAL CONCLUSIONS.

Facts are not at hand to warrant an unreserved statement of the relation existing between ore No. 2 and the Hagy body; at the same time, it is thought that they are probably parts of a single vein which has been separated by faulting. The existence of a fault is surmised from the knowledge that in the Warwick mine limestone conglomerate forms the hanging wall of the vein at least as deep as the 555-foot level, whereas in the upper levels of the California mine the same rock lies above the Hagy vein. If, then, the Warwick vein holds its position just beneath the conglomerate as it extends upward into the California mine, and if the Hagy vein holds its position beneath the conglomerate as it extends downward from the 200-foot level to the 390-foot level there can be no doubt that both the ore layer and the overlying conglomerate have been offset along a fault break. The same conclusion would follow if it were found that conglomerate forms the hanging wall both of ore No. 2 and of the Hagy vein on the 390-foot level of the California mine. The horizontal displacement along the fault appears to be about 125 feet (Pls. VIII and XVI).

On the assumption that there is a fault and that the Hagy vein continues to dip about 65°, as noted on the map (Pl. X) at the end of the 390-foot level, California mine, the positions of the foot wall on the 555-foot, 610-foot, and 683-foot levels will be approximately as shown by Pl. XVI.

On the 390-foot level in the California mine, according to Mr. Richards, exploration was carried in lean ore for 50 or 60 feet toward the north along the strike of the vein. This makes it appear that mineralization dies out in this direction. A similar decrease in values having been found in a 100-foot westerly drift from the middle slope, the intervening ground has been judged to be barren. Whether it is really so or not of course can not be decided without actual exploration, but the existence of a fault break or of several breaks between the workings of the California mine and those of the Phoenix mine on the East vein is strongly suggested by the relative positions and different strikes of the Hagy and East veins. A good idea of these features may be obtained from the plan giving the projected positions of the several veins on a level surface 400 feet below the top of Gabel No. 1 shaft (Pl. VIII). Mr. Richards states that on the lowest level of the workings on the East vein good ore continued east of the upper slope about 100 feet, beyond which lean ore was penetrated for perhaps 50 feet. On the middle level, 43 feet vertically above, mining was continued toward the east for 150 feet, and on the upper level, 43 feet higher, good ore was found for fully 500 feet. The total length of the ore body on the upper level was about 750 feet. Corresponding roughly with the bottom of the minable ore, which is found farther and farther west as depth is gained, the upper edge lies more than 100 feet east of the middle slope on the upper level, about 25 feet east on the middle level, and some distance west of the slope at the bottom of the mine. It is thus apparent that, in addition to its southeastern dip, the ore shoot pitches toward the south, and also that if this pitch continues the ore body must pass into the block of ground bounded by Third street, the mineral-reserve line, and the railroad. How far it may persist in this direction can not be suggested. It may or may not extend as far as the ore horizon remains unbroken.

It is strongly suspected, as already stated, that at least one displacement of the ore horizon—that is to say, the surface between the limy strata and the limestone conglomerate—exists between the middle slope and the workings of the Hagy vein of the California mine. Three faults with horizontal displacements equal to that of the fault supposed to exist between the Warwick and Hagy ore bodies would suffice to throw the ore horizon from the place it occupies in the California mine into the observed position of the East vein. (See fig. 7.) If the Hagy vein is ever found in the lower workings of the Warwick mine, further prospecting in the direction of the estimated downward extension of the East vein would seem warranted. The intervening block of ground may not contain workable ore near the surface, but is perhaps more likely to carry ore bodies as depth is gained, because the mineralizing waters which produced the ore are believed to have come from below.

The chances of finding the Hagy and East veins above the lowest level of the Warwick mine are thought to fully warrant explorations along the lines of the foregoing suggestions, but the ground that offers the strongest inducement for exploration is that which lies beyond the Warwick and Gabel workings in the direction of the dip of the Warwick ore body. No extended argument is needed to show the advisability of testing the further persistence of an ore body like the Warwick or Black vein, which has been followed along its course almost continuously (though swelling and pinching) for 1,000 feet and along its dip for 800 feet, with no signs of failure in the lowest levels that have been opened. The map and cross sections (Pls. X–XV) which accompany this report afford adequate data for laying out an advantageous plan of prospecting the veins by means of the diamond drill.

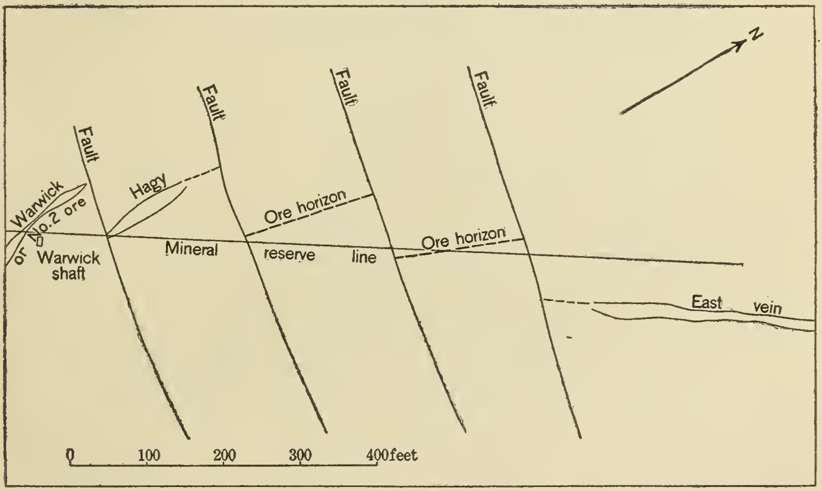


FIG. 7.—Ideal sketch showing possible type of structure in ground between Hagy vein and East vein. Datum of plan, 400 feet below top of Gabel No. 1 shaft.

The theory which has been developed concerning the origin of the Boyertown ore bodies is based on the analogies between these deposits and those of similar character at other places in the State, each of which exhibits a close dependence on adjacent bodies of intrusive diabase. It is noteworthy that all the ore bodies except the East vein lie just beyond the termination of the diabase sill which occurs along the northwest side of Gabel Hill. Apparently underground the sill dips with the bedding of the invaded rock and the edge which it presents toward the north pitches steeply in such a direction that it passes beneath the Warwick and Gabel workings. The Blue vein in the Gabel mine appears to follow the upper surface of the sill, but the Rhoades vein seems to lie against its blunt edge. In the

Gabel mine more than 100 feet of limy strata lie between the diabase and the conglomerate which caps the Black vein, but all indications on the surface favor the conclusion that the conglomerate extends northward almost if not actually to the walls of the diabase. As in the mine it appears that the diabase follows the stratification of the limy beds, the near approach or actual contact of the conglomerate and the diabase at the surface signifies one of two things—either that the intrusive mass cuts across the stratification above the point where the contact is penetrated by Gabel No. 1 shaft, or that the parallelism between the stratification of the Paleozoic and Mesozoic rocks, which apparently exists elsewhere in the mine, does not hold in this place. A plausible suggestion of what the relations may be in depth is illustrated in fig. 8. The presence of several sills south of Boyertown, as shown on the sketch map, the manner in which these sills terminate, and the probable existence of an underlay of diabase beneath the structural basin which has been described all suggest the validity of the assumption that one or more buried sills exist in the region southeast and east of the Boyertown mines.

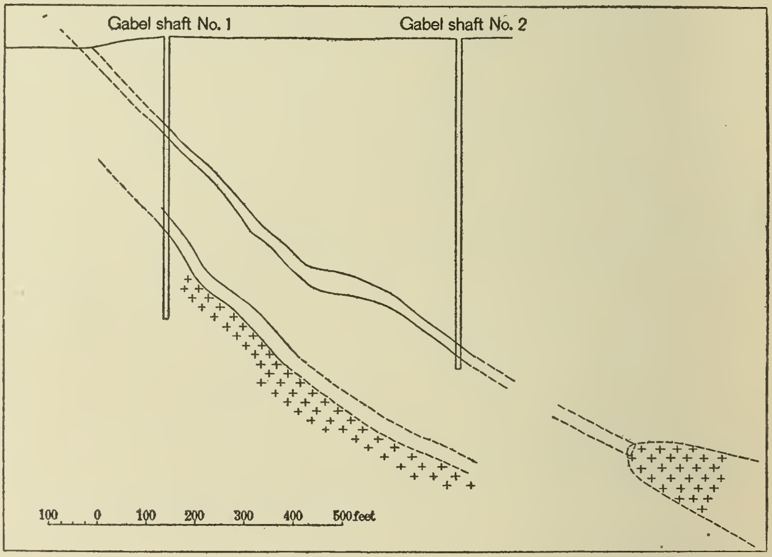


FIG. 8.—Sketch section illustrating possible relation of Black vein to buried edge of a diabase sill at Gabel mines.

The emergence of a minor intrusion of diabase near West Swamp Creek, 1 mile northeast of New Berlinville, and of a great mass east of Bechtelsville suggest that the edges of the sills representing the upward limit of intrusion on the northwest side of the synclinal basin probably lie at no great depth and not very far back (southeast) of the boundary between the Mesozoic area and that occupied by the older formations. If the presence of the buried sills in this vicinity were known to be a fact, and if the place could be determined where any one of them penetrates strata corresponding to those in which the Boyertown deposits occur, the existence of a series of iron-ore deposits in the limy strata near the diabase might be suggested. The absence of knowledge on these two points leaves the whole question in the light of a speculation, with the hazards rather too great to justify recommending the expenditure which would be required to make a practical test. The imaginary position of the upper edge of the supposed sill is shown in plan on the sketch map, fig. 9.

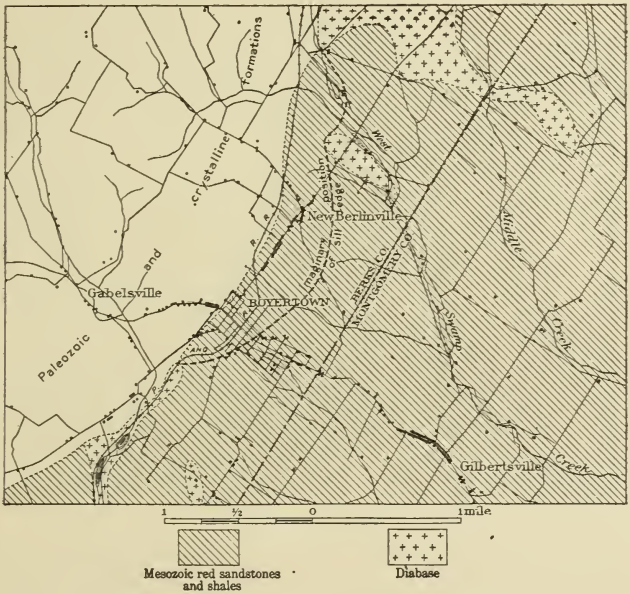


FIG. 9.—Geologic sketch map of vicinity of Boyertown, showing imaginary position of edge of buried sill.

DEPOSITS SOUTHWEST OF BOYERTOWN.

South of the Boyertown mines the northwest slope of Gabel Hill is formed by diabase, the hill itself and the connecting ridge for a mile or more toward the south being formed by baked and indurated shales and sandstones. At the surface this mass of diabase ends as an apparently blunt wedge south of the ground in which the ore deposits have been found, and as nearly as can be determined it comes to the surface just at the base of the Mesozoic beds where they overlap on the ore-bearing strata. In this position the diabase, having the form of a sill, extends for three-fourths of a mile southwestward and then, turning down the valley of Ironstone Creek, cuts back into the Mesozoic area. The western edge of this sill has not been seen at any place because it comes to the surface beneath a mantle of loose débris, but its eastern contact was encountered at the old Brower iron mine on the hill slope opposite the upper end of Wren's ice pond, about half a mile southwest of the Rhoades mine. The Brower ore at this place was discovered in a post hole.

Richard Richards, of Boyertown, who had charge of this property in 1857 and 1858, states that he extracted more than 2,000 tons of magnetite ore from an irregular layer having a northeast-southwest strike, a dip of 35° or 40° SE., and a maximum thickness of about 8 feet. The mine was worked by means of a tunnel and two shafts, and ore was stoped from two levels to a depth of about 70 feet and to a length on the strike of about 50 feet. Examination of the locality shows that the ore layer occurred very near if not exactly in contact with the upper side of the diabase sill, under a hanging wall of flinty baked shale or sandstone. Taken by itself the occurrence of ore at this place is an all but evident instance of ore segregation during igneous or so-called contact metamorphism, and considered in the light of the many like deposits closely associated with intrusive diabase at other places it must be accepted as a deposit of this variety.

About 300 yards southwest of the Brower mine, back of the J. Wren house, a short tunnel with its mouth in diabase was started toward the contact, but no information has been obtained concerning what was found at this place, nor concerning a shaft lying between the Wren tunnel and the Brower mine, shown on the topographic map of the Second Geological Survey of Pennsylvania.

About one-fourth mile southwest of the Rhoades mine, on the hill slope about 50 feet above the level of the railroad track, a shaft (known as the Rhoades and Grim shaft) has been sunk to a depth of 40 or 50 feet, to judge from the material on the dump. Nothing but diabase seems to have been encountered at this place. East and somewhat north of this shaft a tunnel of unknown length was run into Gabel Hill, but no person was found having any knowledge of this work. The mouth of the tunnel is situated very near the eastern or upper edge of the diabase sill, and it seems that Mesozoic strata must have been penetrated.

It is not at all unlikely that other masses of ore like those of the Brower mine exist along the east contact of the sill, but as no limy strata are known to occur on the upper side of the diabase, this ground is not regarded as offering much inducement for prospecting. West of the diabase, conditions are probably more favorable, on the supposition that the strata which carry the Boyertown veins are here in contact with the under side of the sill, but the valley of Ironstone Creek is not a favorable place for making excavations, and it seems that any exploration of the under side of the diabase should be undertaken by means of the diamond drill.

DEPOSITS NORTH OF BOYERTOWN.

About 2 miles north by northeast of Boyertown there has been some exploration for iron ore on the south side of the group of diabase hills southeast of Bechtelsville. The position of two shafts is shown on the topographic map of Berks County, issued by the Second Geological Survey of Pennsylvania, though no essential data are given in the Berks County report beyond the statement that some excellent ore was taken from an opening known as the Gilbert shaft. The shafts mentioned were not found during the present investigation, but from their indicated position they are situated within Mesozoic strata, which come up onto the diabase rock from the south.

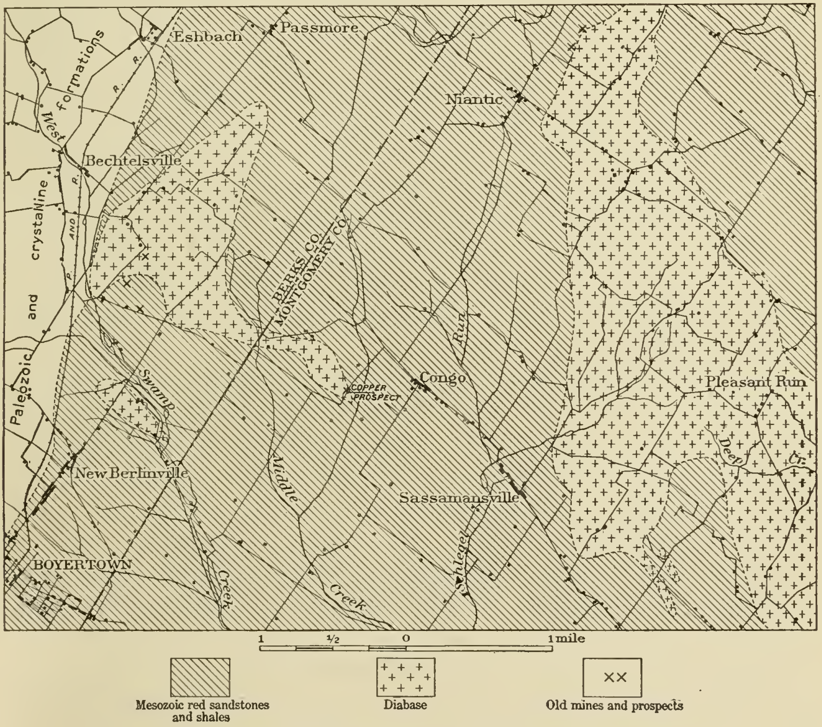


FIG. 10.—Geologic sketch map of region northeast of Boyertown.

The diabase covers a roughly triangular area of nearly 2 square miles, which lies between West Swamp Creek and a tributary known as Middle Creek. From the southeast corner of this area an arm extends for about 1½ miles toward the southeast. The mass of diabase is nearly surrounded by Mesozoic strata, which appear to lap onto it from the east and from the south. (See fig. 10.) On the northwest the structural relations are obscure, but from the rock fragments scattered over the fields the Mesozoic rocks are known to be present along the base of the hill above the wagon road to a point within one-fourth mile of the bridge across West Swamp Creek. Near the turn in the road, a short distance northeast of this bridge, blue Paleozoic limestones are exposed, and above them baked shales, which may belong to the Mesozoic. This shale seems to dip toward the hill at a low angle, as if it would pass beneath the mass of diabase which outcrops a short distance up the slope. The blue limestone is not metamorphosed to any marked degree.

On every side of the diabase the Mesozoic rocks, including shale, sandstone, and limestone conglomerate, have been considerably baked, and this induration extends in places as far as one-half mile from the contact. Loose fragments of limestone conglomerate containing abundant spangles of hematite may be found at several places along the ridge east of Middle Creek, and similar material is abundant on the hill slope about 1 mile southeast of Eshbach. On the south side of the diabase hills both specular hematite and magnetite were noted in material revealed in a cutting along the east-west road a few hundred yards west of the crossroads 1¼ miles northeast of New Berlinville. This locality is near one of the old prospecting shafts mentioned above.

Although the presence of hematite in the baked rocks which surround the diabase shows that certain conditions favorable for the formation of ore existed, it does not seem that any large bodies of ore are likely to be encountered in the Mesozoic strata. The exposures are not sufficient to indicate how much limestone conglomerate exists in the neighborhood, but it is probably not present in any such amount as at Dillsburg, York County, where magnetite ore deposits are associated with beds of this rock in the vicinity of diabase intrusions.

Near the diabase there is only one exposure of the Paleozoic limestone which is known to occupy the valley lying west of the diabase hills, so that almost nothing is known of the structural relations of this rock to the Mesozoic strata and to the diabase. It is probable, however, that the limestones are here overlapped by the Mesozoic strata in much the same way as in the vicinity of the Boyertown mines, and if this is so there is a possibility that the ore bodies may exist in depth beneath the Mesozoic rocks which occur west of the diabase mass. Though this point could be readily tested by a series of drill holes along the western portion of the diabase area, such exploration would be regarded as a hazardous project from a practical standpoint.

Iron ore is said to have been extracted from workings known as the Fegley mine, situated well within the diabase area on the north side of the little brook about one-fourth mile north of the Gilbert shaft. A suggestion concerning the manner in which the ore occurs in this place was obtained from material on the dump at the tunnel mouth. A large fragment of diabase was found, on one side of which there was a coating of ore 1 inch thick composed of crystalline magnetite intergrown with a minor amount of feldspar. Appearances indicate that the magnetite was segregated in a crevice traversing the diabase. There is no sharp division between the rock and the ore, a fact which suggests that the magnetite and accompanying feldspar may have been deposited by vaporous solutions derived from the deeper-seated part of the diabase mass shortly after the period of intrusion.

In many places the diabase intrusions in the Mesozoic area contain very considerable amounts of magnetite as a mineral constituent, but this is the only place that has come to the writer's attention where magnetite has been found segregated in a definite vein inclosed by the igneous rock. This occurrence has a bearing on the general problem of the genesis of deposits of the Cornwall type, affording good evidence that the diabase rock could have been the actual source of the ore-forming solutions as well as of the energy which caused the circulation of the mineralizing waters. Elsewhere, though the influence of the diabase intrusions is everywhere noteworthy, it has not been possible to show definitely that the solutions have emanated from the intrusive rock.

A shallow pit has been sunk in search of copper ore in a road-metal quarry beside the wagon road half a mile west of Congo post-office, near the end of the arm of diabase which extends toward the southwest from the main triangular area. In the walls of this pit may be seen a veinlet about an inch wide, composed mainly of hornblende and feldspar containing scattered bunches of chalcopyrite. The hornblende of the vein appears to have grown out from the walls of a crevice, and the material of the vein is thus closely knit to that of the inclosing rock, as in the magnetite vein described above. It is suggested that this veinlet was formed in a manner similar to that suggested for the magnetite vein. In a recent paper on the copper deposits of New Jersey by J. V. Lewis[a] the source of this metal is believed to have been the diabase intrusions which in each place are associated with the ore occurrence.

JONES MINE.

The Jones mine, also known as the Warwick mine because it was formerly worked by the Warwick Iron Company, is situated about three-fourths of a mile east of Joanna station and 1¼ miles northwest

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[a] Copper deposits of the New Jersey Triassic: Econ. Geology, vol. 2, 1907, pp. 242–257.

of Elverson, on the Wilmington division of the Philadelphia and Reading Railroad. (See Pl. XVII.) This mine is in Berks County, about 4 miles west-northwest of the Warwick mines in Chester County. Part of the description of the Jones mine by H. D. Rogers is here given:[a]

> The chief mine is an open excavation covering rather more than 5 acres, and there is another to the south of it covering about 1 acre [Kinney mine]. Magnesian limestone bounds the ore on the northern edge of the principal excavation. Here there is a mine shaft 180 feet deep * * *. The shaft enters the limestone at a depth of 50 feet, and a boring 20 feet from the bottom of the shaft is still in this rock.
>
> A dike of trap rock cuts the ore-bearing strata near the southern side of the pit and produces phenomena precisely identical with those caused by the trap dikes in the Cornwall-Lebanon mines, converting the ore to a more highly crystalline form and endowing it partially with magnetism. As in every such instance, the ore is richest and purest adjacent to the trap rock. This is equally the case in the southern or smaller mine. The strata dip N. 30° W. at about 20°; and in the northern bank of the large mine we may perceive the Auroral limestone regularly overlying the upper beds of the Primal slate, containing or consisting of the ore. * * * In this mine, as in that of Cornwall and that of Lebanon, some of the ore contains a small amount of copper.

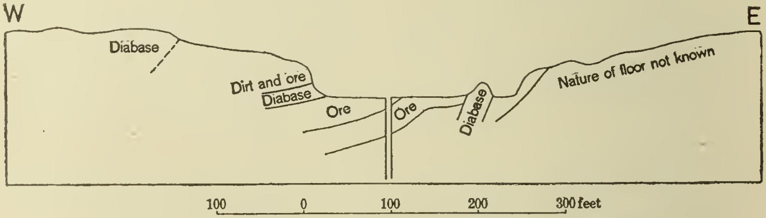

Fig. 11.—East-west structure section, Jones mine (along line *A–B*, Pl. XVIII).

A large-scale topographic map of the vicinity of the mines by J. H. Harden (reproduced here as Pl. XVIII) accompanies the report by D'Invilliers on the geology of Berks County, but no description of the mine is given in the text. However, something of the geology and structure of the mines is indicated in cross sections which accompany the map. These data have been used in constructing the revised cross sections here given (figs. 11, 12, and 13).

The Jones mine and the smaller Kinney mine adjacent lie in the isolated area of Paleozoic limy strata, which are supposed to belong near the base of limestone "No. II" of the Pennsylvania section. As at Boyertown and Cornwall, there is apparently interbedding of limestone and limy shale, the latter being largely changed to ore, while the former exhibits a very moderate degree of metamorphism. Though the pit is now flooded, it is known from dips recorded on the Harden map that in the Jones workings the ore strata are considerably con-

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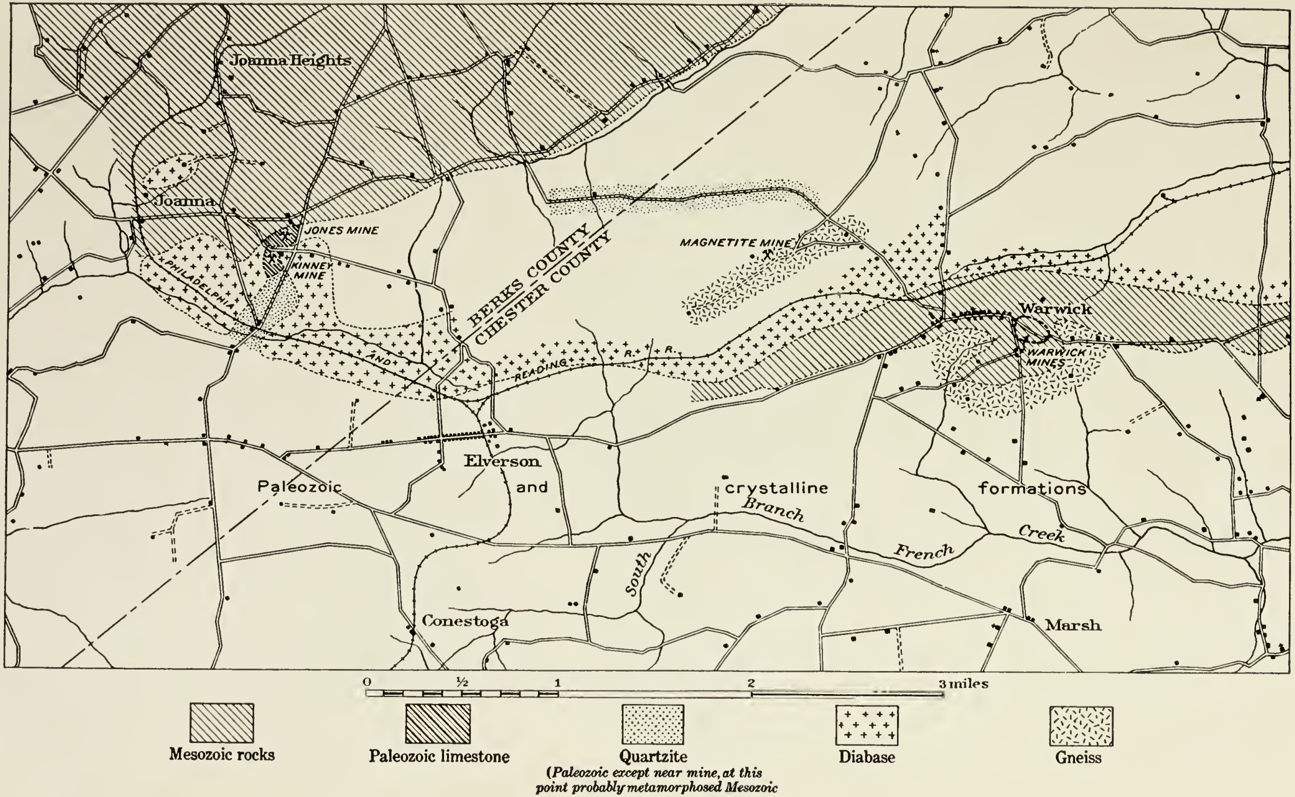
[a] Geology of Pennsylvania, vol. 1, 1858, p. 182.



SKETCH MAP SHOWING GEOLOGY IN VICINITY OF JONES AND WARWICK MINES, BERKS AND CHESTER COUNTIES, PA.
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torted, the general direction of dip, however, being toward the west-northwest. In the northern pit the ore dips 16° N. 55° W. "Above the ore is a limestone bed conformable to it, about 12 to 15 feet thick, and above that still is a conformable light-green earthy shale."[a]

The ore-bearing strata are overlapped on the north by reddish Mesozoic conglomerate, containing large quartzite pebbles. East of the large mine the nature of the bed rock can not be determined, but presumably the limy strata run out for several miles in this direction. On the State Survey geologic map of Berks County the "No. II" limestone is represented as a narrow strip extending through the Jones mine toward the east-northeast as far as Hopewell furnace, and though no outcrops are to be found it is very likely that these strata underlie the accumulation of surface débris along the topographic depression which separates the red conglomerate and sandstone hills on the north from the quartzite hills on the south.

Two bodies of diabase occur on the south side of the Jones pit and are exposed along the edge of the excavation. Between them are limy strata in the southwest corner of the pit, and these beds probably extend through to the Kinney mine. South of the Kinney pit quartzite fragments occur in the soil, and near the railroad crossing this rock may be seen in place. It is not known whether the quartzite belongs to the Mesozoic or to the Paleozoic "No. I" sandstone. The area which it occupies is limited on the west and east by the masses of diabase. The western mass is exposed along the railroad for about one-half mile; the other may be traced eastward to the falls of French Creek and for several miles beyond. The mass of diabase represented on the Berks County map just north of Joanna station was not visited by the writer. Several minor masses of diabase, dividing the ore, were encountered in the mine workings. The sketch map (Pl. XVII) shows the distribution of the various rocks in the vicinity of the Jones and Warwick mines.

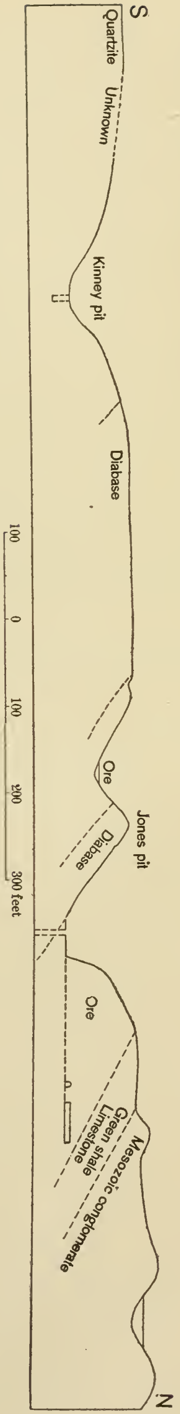

FIG. 12.—North-south structure section, Jones and Kinney mines (along line *C–D*, Pl. XVIII).

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[a] Willis, Bailey, Tenth Census, vol. 15, 1886, p. 225.

The iron minerals of the Jones ore are magnetite and pyrite, and some of the ore contains chalcopyrite. In the richer material the magnetite and pyrite occur in more or less crystalline form, accompanied by calcite or dolomite, the whole forming a rather granular aggregate. Such ore does not betray its origin; but lean material, of which there is a great amount on the old dumps, shows clearly that the iron minerals have been formed by a chemical substitution or replacement of limy strata. Blocks may be seen showing all degrees of replacement and still retaining their stratification. Brecciation and cross veining, which are noteworthy features at Cornwall, are not observed in the material from the Jones mine. As at Cornwall, chlorite is an abundant mineral in the waste, but only minor amounts of this mineral occur in the usable ore. A few blocks of limestone containing small garnets were noted.

The important rôle of the intrusive diabase as an element in the local geology is shown by the extent of the rocks indicated on the geologic sketch map (Pl. XVII). The writer believes that the segregation of the ore resulted from the intrusion of this rock, though evidence sufficient to establish this theory has not been found. That ore minerals were being deposited after the diabase had been injected is indicated by the presence of magnetite, pyrite, calcite, and chlorite in cracks in the igneous rock and entirely surrounding fragments of it. Blocks showing these relations, which presumably came from one of the minor masses of diabase encountered in the workings, were found near the engine house, on the north side of the Jones mine.

FIG. 13.—East-west structure section, Kinney mine (along line *E–F*, Pl. XVIII).

From existing descriptions it appears that the overlapping Mesozoic strata are separated from the ore body by barren shale and limestone, a relation which makes it difficult to believe that the leaching of these ferruginous sediments could have furnished the iron for this large ore body and which leaves the way open for the suggestion that the diabase was the source of the mineralizing waters and of the iron that they contained.

The discussion of the possible occurrence of other ore deposits in the vicinity will be deferred until the detailed geologic map of the district is available. Professor Bascom, of Bryn Mawr College, is now engaged in studying the geology of the Honeybrook quadrangle, in which the mines are situated.

The following note is copied from Frazer:[a]

On the lands of the Warwick reserve, 2 miles southeast of the Joanna furnace and about 1½ miles east of Morgantown and ½ mile south of the narrow belt of

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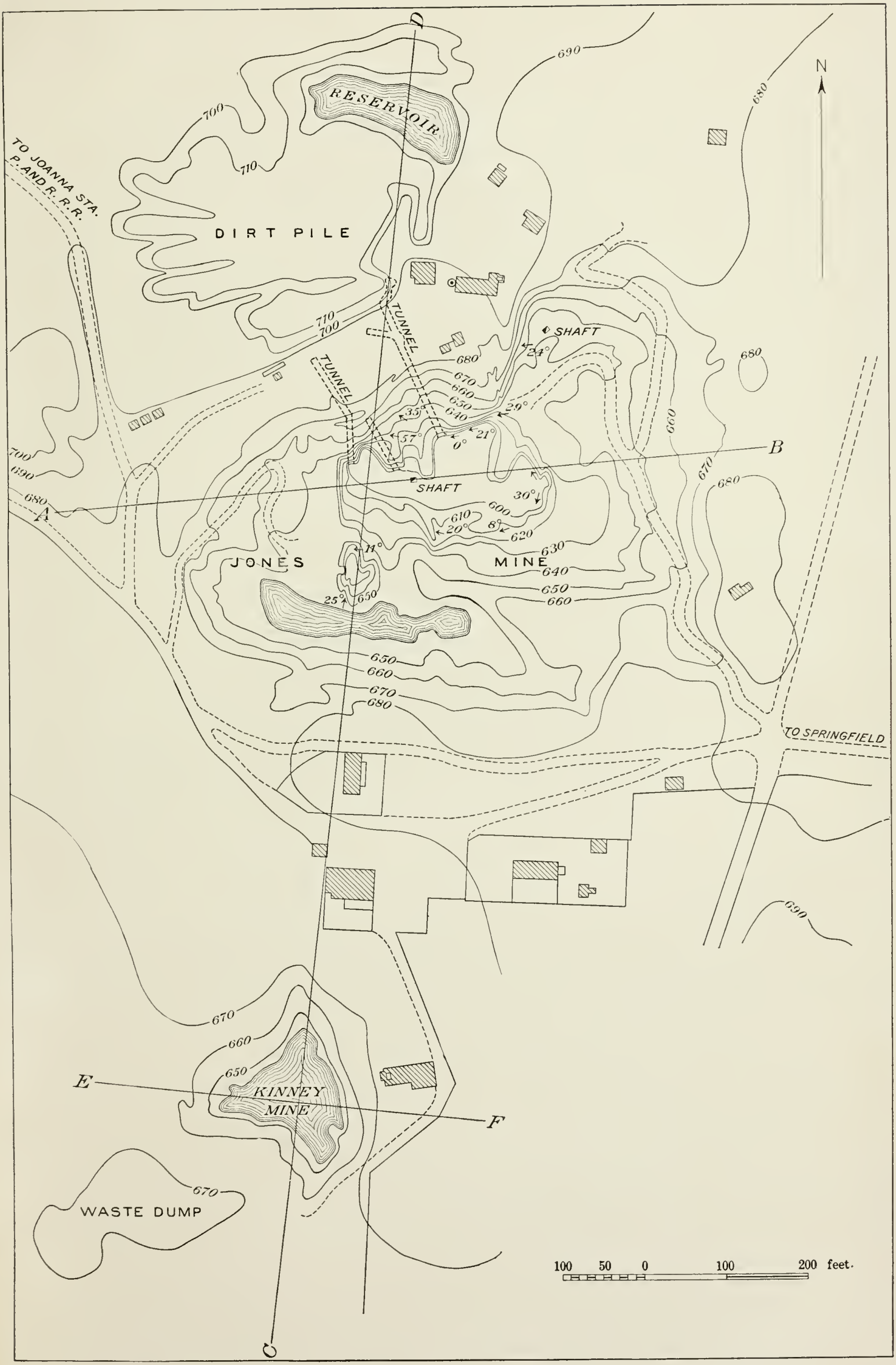
[a] Frazer, Persifor, jr., Second Geol. Survey Pennsylvania, Rept. CCC, 1877, p. 237.



TOPOGRAPHIC MAP OF VICINITY OF JONES AND KINNEY MINES, BERKS COUNTY, PA.

> limestone which leaves the large Lancaster limestone tract and passes through Morgantown, * * * in Berks County, is an exploitation for ore.. * * * The material thrown out of the pit appears to be an altered mud rock, alongside of which occurs ore very like that of Cornwall and some of that from Dillsburg.

WARWICK MINE.

The old workings of the Chester County Warwick mine are situated just east of Warwick, formerly known as St. Marys. (See Pl. XVII.) The deposit appears to have been nearly exhausted prior to 1875, although there was some mining as late as 1882. Little can be made out by an examination of the ground at the present time, but such features as can be observed correspond with the following description published by H. D. Rogers in 1858:[a]

> This extensive and interesting body of iron ore, situated just southeast of St. Mary's Episcopal Church, is in reality not a genuine lode or igneous intrusive vein, though the ore derives some of its characters from intrusive igneous action, but it is a bed or deposit at the base or very near the base of the middle secondary red sandstone, which here laps upon the gneiss. The explored extent of this bed, hitherto penetrated only near its outcrop, or where the overlying strata are shallow, is already very great, amounting to many acres. The ore deposit observes everywhere a very gentle dip, and seems to undulate in two or three waves across the tract which includes it. A somewhat conspicuous anticlinal change in the dip occurs to the south and southwest of the present main engine shaft by which the mines are dried, and there is every indication that the ore basins are both south and north of this saddle. Though the basin to the south of it is intersected, and the ore in one place cut off or thrown out to the surface by the intrusion of a wide dike of trap rock, there is strong reason to infer that the ore occupies a comparatively wide though perhaps shallow basin, north and northeast of the engine shaft [fig. 14].

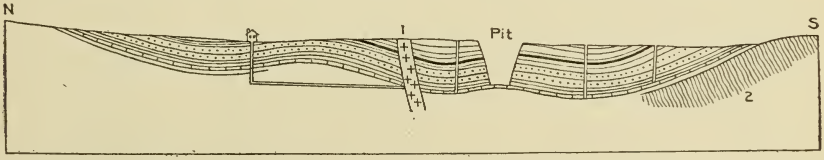


FIG. 14.—Structure section at Warwick mine, Chester County. After H. D. Rogers. 1, Diabase; 2, gneiss.

> Besides this intrusion of trap, there seems to exist here injections of serpentine and other mineral matters, and at one point, just by the southwest margin of the ore bed, there exists a very singular intrusion of mineral matter penetrating the ore and altering, in a remarkable manner, the conglomeratic layers which here constitute the southeast border of the red sandstone formation. This rock is greatly baked and changed in aspect, includes numerous spheroidal bunches of segregated crystalline mineral matters (some of them in the form of hollow geodes), and is intersected besides with numerous strings, or little veins. In these spheroidal nests occur beautiful linings of crystallized epidote and other minerals, and bunches of large crystals of the fine variety of garnet called melenite. The list of the minerals occurring here is not extensive. The

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[a] Geology of Pennsylvania, vol. 2, 1858, pp. 708–709.

conditions under which they present themselves are such as strongly to impress the geological observer with the notion of their having been introduced chiefly in a vaporous state, or by sublimation, for in many of these hollow spheroids we can detect no connection whatever between the interior or even the exterior walls of the geodes and any external veins or filaments of injected matter, such as any other theory would demand for the introduction of the materials of the crystalline minerals here so curiously insulated.

The bed of iron ore for which this locality is chiefly noted is of very variable thickness, fluctuating from 1 or 2 to 9 or even 17 feet. As illustrating the general levelness of this undulating deposit, it may be stated that in no place has it been required to sink deeper than about 60 feet to reach the ore, while generally the covering is so thin that the ore is conveniently procured by merely stripping off a thickness of a few feet or yards of loose disintegrated rock. The average richness of this ore may be stated at about 45 per cent of metallic iron, though much of it exceeds 50 per cent. It is somewhat sulphurous; and when care is not employed in selecting it for smelting, and in the after processes, it tends to produce a hot-short or red-short iron, but when carefully manufactured it yields an excellent metal. The annual product of the Warwick iron mines for fifteen years was not less than 4,000 tons, and the average yield for the past twenty years has been 6,000 tons. In the year 1853 the amount mined reached 12,000 tons. These ore pits have been wrought for the last one hundred and twenty years, and there would seem to be at present really more ore within sight than there has ever been before at any one time. The present average cost of mining this ore is about $1.50 per ton. * * *

This ore is intermediate in its physical characters and aspect between the true brown hematite and the magnetic oxide of iron. As, on the view of its having been originally hematite but subsequently altered by igneous action, we might naturally anticipate, those portions of it which have undergone the highest degree of metamorphic influence are of a gray color, quite crystalline, and partially endowed with magnetic force, whereas the less altered parts are nearly in the condition of a compact, closely cemented hematite. Minutely interstratified with this ore there occurs more or less earthy matter, apparently laminæ of indurated slate or shale; and when the layers of this rock are thick, and they disperse the ore, they interfere materially with the economical prosecution of the mine. This slaty or earthy matter tends, furthermore, by intimately mixing itself in with the finer granular ore, seriously to reduce the richness of the mingled mass in iron.

Specimens of the metamorphosed conglomerate described by Rogers may be found in the old mine pits. Green hornblende and brown garnet, calcite, pyrite, specular hematite, and magnetite are among the secondary minerals observed. Epidote was not noted. No geologist familiar with the common metamorphic alterations of sedimentary rocks adjacent to intrusive igneous masses can see this material without regarding it as a product of contact metamorphism involving the action of heated water. In the writer's opinion the features of the ore specimens which have been examined do not suggest that the magnetite of the Warwick deposit has been produced from brown hematite by heat metamorphism, as proposed by Rogers, but it seems that hematite, magnetite, and pyrite must have been introduced into their present situation and must have been formed contemporaneously.

In conformity with the general theory concerning the origin of other deposits of the Cornwall type, it is suggested that the ore minerals were introduced by solutions sent into circulation by the intrusive diabase that occurs north of the mines. This view is justified by the baked condition of the Mesozoic strata throughout the strip which lies south of the diabase mass and by the observed alteration of the conglomerate rock, so well described by Rogers. There is no evidence to show whether the iron was leached out of the Mesozoic strata or was furnished by the igneous rock.

The geologic relations observed at the Warwick mines continue for some distance both east and west. It is thought not improbable that similar ore deposits may exist at other points, between the east-west mass of diabase and the south edge of the Mesozoic strip which marks the overlap of the sandstone upon the ancient gneisses. Bodies of iron ore may lie in a position similar to that of the Warwick deposit and still not extend far enough south to have been brought to light along the edge of the Mesozoic strip. If erosion had been only slightly less than what is actually observed in the neighborhood of the old mines the edge of the ore deposit would not have been stripped of its cover and would not have been discovered except by some chance excavation of considerable depth. On the other hand, the removal of a little more cover elsewhere along the line of overlap might have revealed deposits similarly situated, of which, under existing conditions, there are no surface indications. Although it is regarded as possible that systematic drilling might lead to the discovery of new ore deposits in the ground indicated, the undertaking of such extensive explorations as would be required can hardly be recommended as a business venture at the present time.

About 2½ miles east of the Warwick mines and just north of Knauertown indications of iron ore were prospected many years ago. The geologic position is identical with that of the Warwick deposit. On the basis of the theory that the mass of diabase which lies north of this place has been the inciting cause of the deposition of iron minerals, it is not unreasonable to expect that these indications may lead to a better deposit of ore at a greater depth beneath the hill.

YORK COUNTY DEPOSITS.

GENERAL STATEMENT.

Iron ores like those of the Cornwall mines occur at several localities in northern York County. The principal group of mines is situated about 1 mile east of Dillsburg, and a second smaller group is located just south of Yellow Breeches Creek near Grantham crossing, on the Philadelphia and Reading Railroad. Specular hematite with some associated magnetite has been worked at Minebank schoolhouse, about 2 miles southwest of Wellsville, and minor pockets and indications of ore have been found at various other localities. Most of these occurrences had been discovered prior to 1873 and are described or mentioned in Report CC of the Second Geological Survey of Pennsylvania[a] and in the Annual Report for 1886.[b]

In 1907, when the writer visited the field, no mining was being done, so that such data as could be collected concerning these interesting deposits have been procured from examinations of the surface and from conversation with persons familiar with the underground operations. Since the publication of the reports mentioned above only two new mines have been opened, but considerable ore has been taken from several of the old ones.

Two opinions have been expressed in published descriptions regarding the geologic position of the Dillsburg deposits. They have been held on the one hand to lie in Mesozoic rocks and on the other to occur in Paleozoic strata, as at Cornwall. Detailed study of the general region now shows that all the deposits are inclosed by the younger set of rocks, as stated by D'Invilliers.

The Grantham mines lie very near the edge of the Mesozoic area; those of the Dillsburg group are situated from 1½ to 2½ miles within the northwest boundary, and the mine southwest of Wellsville lies 6½ miles within the Mesozoic belt. (See Pl. XIX.) No bodies of ore and no strong indications of ore occurrence have been found except where the strata have been greatly metamorphosed or baked in proximity to intrusive masses of diabase. This association points definitely, as do all other occurrences of iron ore of the Cornwall type, to the belief that the ores are connected in origin with the intrusion of the diabase. However, the mere presence of diabase in a locality is by no means sufficient to insure the presence of ore near by; otherwise, York County would be unsurpassed as an ore field because of the great extent of the diabase masses within her borders. The scattered or limited occurrence of ore deposits points to a second condition as essential to the formation of ore, and it is believed that this condition is the presence of calcareous (or lime-bearing) rocks in the vicinity of intrusive masses of diabase. In all the more important mines of the Dillsburg group and at Grantham beds of limestone conglomerate are found in the workings. At Minebank, also, crystallized limestone is to be found in the mine waste. At Dillsburg many pockets of ore which were mined out years ago and one bed continuous for nearly 500 feet at the surface (McCormick long cut) appear to have been inclosed in baked sandstone. Though there is now no evidence that limestone occurs in these workings, it is possible that the masses of

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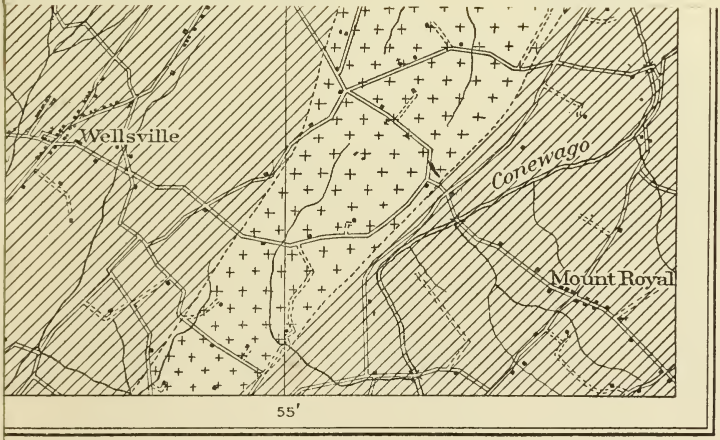
[a] Frazer, Persifor, jr., Report of progress in the counties of York, Adams, Cumberland, and Franklin, 1877, pp. 201-239.

[b] Ann. Rept. Geol. Survey Pennsylvania for 1886, pt. 4, 1887, pp. 1501-1514.



spects

PA.

GEOLOGIC SKETCH MAP OF MESOZOIC AREA NEAR DILLSBURG, YORK COUNTY, PA.

ore represent original bodies of limestone conglomerate which have been converted into iron ore by chemical replacement.

In the vicinity of the Dillsburg mines there are no natural exposures of limestone conglomerate and only along the Philadelphia and Reading tracks near Grantham can this rock be seen at the surface near known ore bodies. In drill holes near the old McCormick workings at Dillsburg the occurrence of limestone has been recorded.

Exposures of rock in place in this region are very few in number, but the distribution of the diabase and of the Mesozoic rocks as a whole can be recognized from the presence of residual bowlders or broken fragments in the soil. It is not possible, however, to decipher any details concerning the make-up of the sedimentary formation. It is supposed that there may be several beds of limestone conglomerate separated from each other by sandstone and shales, but only the presence of the latter can be ascertained from inspection of the soil. Everywhere the materials of the surface débris show evidence of the baking which the rocks have undergone. The absence in the vicinity of the mines of fragments from the limestone conglomerate is no doubt due to the great solubility of this rock compared with the overwash of the more resistant baked sandstone fragments.

Limestone conglomerate outcrops at several places west and southwest of Dillsburg, showing that here it is an important element in the constitution of the Mesozoic formation. In the foothills of South Mountain, northwest of Beavertown, fully 50 feet of the rock is exposed in a large quarry. This quarry has been opened around a sink hole, into which a small brook disappears. A series of sinks may be followed from this place for nearly a mile toward the northeast. Though the sink holes suggest that the conglomerate continues as the bed rock in this direction there are no exposures, because of the heavy overwash derived from the mountain slope, and it is possible that a strip of the Paleozoic limestone sets in between the quartzites of South Mountain and the Mesozoic beds, which lie to the east. In this situation either the limestone conglomerate or the older limestone would be liable to contain underground watercourses and to give rise to the observed sinks. At a quarry on the west side of the York Springs road, about 1 mile from Dillsburg, 12 or 15 feet of conglomerate are seen lying between a stratum of red sandy shale, and massive beds of metamorphosed conglomerate may be seen a mile southwest of this quarry, at the eastern base of the diabase hill, along an abandoned railroad grade. The same rock is said to have been found in several dug wells in the northern and western parts of Dillsburg. A drilled well at the creamery penetrated 80 feet of conglomerate, and at this depth encountered an open cavity. This well overflows during wet seasons. The only exposure noted within the borough limits is just south of the mine railroad at the easternmost street crossing. The occurrences which have been mentioned strongly suggest that west of Dillsburg the broad valley occupied by Dogwood Run and its southern tributaries is underlain by limestone conglomerate. It seems probable also that beds of the same rock are present beneath the meadows east of Dillsburg, between the town and the mines. This is suspected because the conglomerate is known to occur both east and west of the flat, and because the presence of this soluble rock would be a favorable condition for the development of just such a broad basin as exists.

It may be mentioned incidentally that the presence in the soil of débris derived from the South Mountain rocks shows that Dogwood Run formerly flowed across this depression and joined Yellow Breeches Creek by way of Fishers Run.

The geologic sketch map (Pl. XIX) shows the general position of the boundary between the Mesozoic area and the older formations of South Mountain, and also the approximate distribution of the diabase intrusions in the Dillsburg region. The close association of the ore with the masses of igneous rock is well brought out by the indicated positions of the mines and prospects of the district.

DILLSBURG MINES.

INTRODUCTION.

The Dillsburg ore field has a greater extent than any of the other districts which furnish ore of the Cornwall type. Ore has been taken from more than 30 openings, including open pits and underground mines, and these workings are distributed over a zone nearly 1½ miles long and from one-fourth to one-half mile wide.

The annual output of the Dillsburg mines has never been large and the aggregate of the ore shipped is probably less than 1,500,000 tons, the period of production having been about sixty years. The ores have not been in general or constant demand, mainly because they are high in sulphur, but also because their iron content is low in comparison with that of Lake ores. They compare favorably, however, with the Cornwall ore, the use of which has been on the increase for many years. Like the Cornwall ore they must be roasted before going to the blast furnace, except when they are mixed in rather small proportions with other ores. The fact that the Dillsburg ore has found even a limited market at various times during the last twenty years is sufficient ground for believing that if the mines can be shown to be capable of further output no serious difficulty need be expected in disposing of the product. The mines have been worked mainly by individual owners and lessees without sufficient capital to carry development far enough ahead of extraction to justify operation on a large scale. Could the ore fields be brought under the control of interests strong enough to explore the deposits adequately and, if preliminary work should warrant, to develop them on a large scale, it seems likely that they might be brought again into successful operation. Even a moderate tonnage, if assured for a period of years, might warrant the maintenance of roasting furnaces, or, what might prove more advantageous, the installation of some concentrating process to raise the grade of the ore as it comes from the mine. Geologic considerations favor the persistence of the deposits in depth and point to the probability that ore bodies in addition to those now known might be discovered by systematic prospecting.

It is hoped that the present description and the geologic map of the district (Pl. XX) that has been prepared may aid in the future development of the deposits.

DESCRIPTIONS OF MINES.

Logan mine.—The shaft of the Logan mine, which is the most recent opening in the district, is located about 200 feet north of the wagon road leading from Dillsburg to Stevenstown. It is situated just within the outcrop of a diabase sill about 200 feet wide, which crosses the road east of the forks. Mr. Logan, the owner of the property, was encouraged to open at this place through having observed a strong magnetic attraction determined with a dipping needle. The bottom of the diabase is evidently inclined toward the north at a low angle, for it is said to have been penetrated at a depth of 32 feet. Mr. Logan reports that 7 feet of ore was encountered just under the diabase, and that the floor is limestone conglomerate. The ore bed and the inclosing rocks dip toward the north. The mine was operated for a short time only, so that the extent of the ore body is not known.

North of the shaft the surface slopes gently toward a small stream fed by a spring between the two forks of the wagon road. Sandstone fragments observed along the depression occupied by this stream indicate the presence of a strip of sedimentary rock, which, as it is traced toward the east, curves to the south and crosses the right-hand road just west of the church. It is thought that this band of sandstone may run down the ravine and across Fishers Run to join a similar band which sets in from the west, but this connection can not be established from observation. North of the sedimentary strip diabase appears at the surface and continues without interruption to the vicinity of the Jauss and King mines.

South of the diabase intrusion penetrated by the Logan shaft there is a considerable strip of sedimentary rock, beyond which appears another somewhat wider diabase band. These two masses of diabase come together southeast of the mine. Still farther south there is yet another band of sedimentary rock, and beyond this is the large mass of diabase forming the group of hills south and east of Stevenstown. As already noted, this diabase extends westward to Dillsburg.

Inasmuch as limestone conglomerate occurs at the old Price pit, and also in the Logan mine 1,300 feet to the east, there is reason to believe that the mass of diabase which lies immediately north of both mines is a sill conforming more or less closely with the stratification of the sedimentary rock into which it has been injected. The limestone conglomerate dissolves under the action of the weather, so that its presence can not be determined by inspection of the surface débris. It is very likely that it extends along the contact with the diabase between the Logan and Cox openings, and west of the Price pit, perhaps as far as the next north-south wagon road. There is nothing to suggest how far it may extend toward the east and southeast beneath the diabase sill.

The masses of diabase occurring south of the Logan mine are probably sills, and other beds of conglomerate may be associated with them. If this is the case, it seems very likely that other ore deposits may be present in the country south of the Price, Cox, and Logan mines. Though it may be suggested that surface indications should betray the presence of any considerable deposit of ore in this part of the district, the surface débris is here apparently so thick and so liable to have moved for some distance that the weathered portions of ore beds might very well have been entirely covered. This is particularly true of the strip of sedimentary rocks which lies north of the Logan shaft. Both sides of this strip would seem to offer likely situations for the occurrence of iron-ore deposits. The Logan ore was discovered by means of the dipping needle. This instrument may prove of value in further exploration of this ground.

Cox mine.—The Cox mine is situated about 950 feet west of the Logan shaft, just south of the same diabase sill. The mine was in operation when the Dillsburg field was visited by D'Invilliers, whose report [a] may be summarized as follows:

At the Cox mine, on the Price farm, the engine house is situated just north of the public road. The ore bed is mined by means of a slope about 300 feet long on a bed of magnetic ore dipping about 25° a little west of north. Near by is an abandoned slope descending nearly due north for 280 feet, and in a shaft 125 feet north of the engine house the ore bed was struck near this slope at a depth of about 40 feet. The ore so far as developed seems to lie in a deposit shaped like a shell, the top and bottom of the shell coming together and pinching out the ore on all sides along the strike, as well as along the dip. The average thickness of the bed is 5½ to 6 feet, though in places it swells to 9 feet. Generally it has a gray dolerite trap for a hanging wall and a sandy bastard limestone for a foot wall; but

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[a] Ann. Rept. Geol. Survey Pennsylvania for 1886, pt. 4, p. 1504.

there seems to be no very persistent character for either. The western side of the deposit is more mixed in character than the eastern, and in places the trap wall seems to stand almost vertical, squeezing the ore into a narrow compass. The foot wall in many places appears more like white baked slate rock than like limestone, but contains some lime. In April, 1887, ore was being mined at the rate of 25 tons per day.

West of the slope a small open cut exhibits a bed of rather sandy ore, from which perhaps 200 tons have been taken.

Price mine.—A large pit situated about 250 feet west of the Cox slope is known as the Price mine. The mine is said to have been opened about 1855 and the ore is reported to have been 6 feet thick. Fragments of limestone conglomerate may be seen in a small pile of waste in the pit. The edge of the diabase sill passes just north of the pit and the dip of the rocks is evidently toward the north, as at the Logan shaft and Cox slope. Instead of being in actual contact with the diabase the ore body appears to have been separated from the mass of igneous rock by intervening beds of sedimentary rock. The sedimentary area between the two sills of diabase is much narrower in the vicinity of the Price mine than farther east. The southern sill comes to a blunt termination in the field northwest of and across the road from the schoolhouse.

Grove mine.—About 1,400 feet due west of the Price pit is the mouth of the Grove slope, which was opened in 1873. The dip of the rocks is given in Report CC as 24° N. 10° E. Though rock resembling weathered trap is said to occur at the mouth of the slope, the present writer was not able to find any evidence of other material than sandstone and shale in the vicinity. In the wagon road north of the opening exposures of baked shale are to be seen dipping about 20° N.

About 400 feet south of the slope is an old excavation, doubtless an ore pit, but no information has been procured concerning what was found at this place or when the opening was made. The edge of the east-west diabase mass passes about 300 feet south of the pit.

Prospects near the Price farmhouse.—Mr. Logan, the present owner of the Price farm, states that a bore hole put down in the swamp east of the farmhouse encountered ore at a depth of 75 feet. This hole appears to have been located north of the boundary of the main mass of diabase, and the ore probably lies on the under contact of the intrusive rock. Inspection of the geologic map will show the position of this occurrence with reference to the strip of sedimentary rock occurring north of the Logan mine. It seems that if the diabase contact follows the stratification in this vicinity ore may occur to the east as well as near the Price house, although, as stated previously, the continuity of the sedimentary strip across the creek is not proved.

Indications of ore have been found 700 feet northwest of the farmhouse, just at the edge of the diabase, where the boundary curves toward the north. No other signs of ore are known to have been found between this point and the Bell mine.

Bell mine.—The Bell mine, which was opened in 1875, is situated about midway between the Price pit and the Underwood group of workings. It was last worked about 1902, at which time the pillars of ore were robbed and the mine finally abandoned. From a statement by Frazer[a] that bowlders of hard limestone were encountered in the upper 25 feet of the discovery shaft just north of the entrance to the working slope, it is judged that the ore lies beneath limestone conglomerate. This suggestion is corroborated by the presence of conglomerate in the mine waste, but there can be little doubt that the mass of diabase lies at no great distance above the ore body.

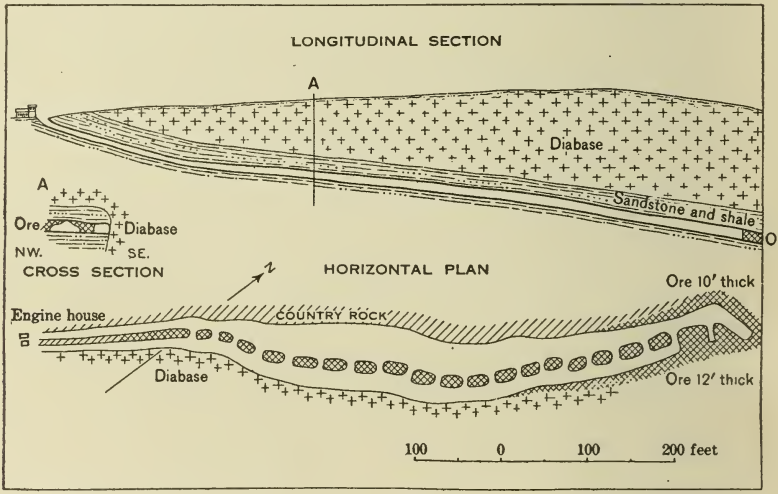

FIG. 15.—Plan and sections of Bell mine, near Dillsburg. From Ann. Rept. Pennsylvania Geol. Survey for 1885, p. 566.

The mine was worked by a slope a short distance south of the main diabase area. The course of the slope is N. 10° E. and its inclination is said to be about 20°, though the cross section given in fig. 15 indicates a lower angle of inclination. In 1883 the slope was about 875 feet long, but it was afterward extended 200 feet or more. The ore body is said to have had the form of a rather well-defined shoot following the dip of the inclosing strata, but limited on both sides along the strike. The maximum width is stated by D'Invilliers[b] to have been 60 feet, and at 875 feet from the mouth of the slope the bed was 10 to 12 feet thick. In fig. 15 the ore is shown to be cut out on the east by diabase (see Pl. XX), and from the relations shown it may

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[a] Frazer, Persifor, jr., Second Geol. Survey Pennsylvania, Rept. CC, 1877, p. 218.

[b] Ann. Rept. Geol. Survey Pennsylvania, pt. 4, for 1886, 1887, p. 1505.

be that the ore body occurs adjacent to a roll in the bottom of the diabase mass where this rock locally cuts across the strata (fig. 16). The course of the diabase boundary at the surface is favorable to this suggestion.

If the suggested structure is borne out by the facts, it is not likely that other ore bodies exist toward the east, where diabase would be encountered, nor toward the west, where, though present, the ore-bearing stratum is probably not mineralized.

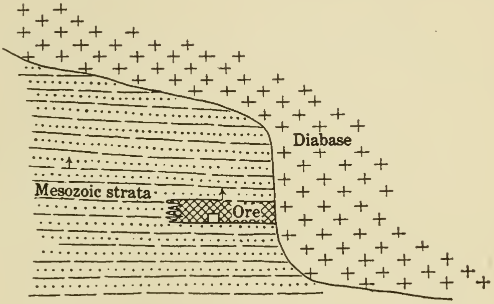

Fig. 16.—Surface plan at Bell mine, near Dillsburg, showing probable structure.

Although it is reported that the bottom of the slope is not in ore, it may be that one of the sides of the shoot has been encountered rather than its bottom. This point may be worthy of investigation at some future time.

When the mine was abandoned the slope was 1,100 feet in length.

About 200 feet south of the Bell slope is an old slope stated by Frazer [a] to have been 180 feet long. From a point 125 feet down the slope there is a 50-foot drift to the east, and from the bottom another 75 feet long to the west. Exposures at the mouth of the slope show fine-grained sandstone as the hanging wall. The nearest diabase is that of the main mass, the edge of which lies about 100 feet to the northeast.

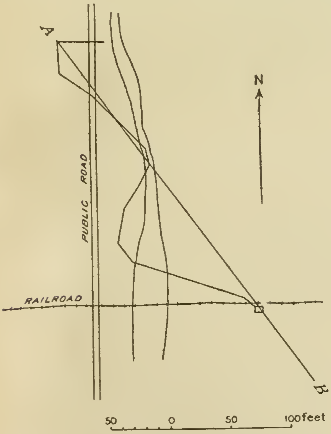

Fig. 17.—Survey of workings at Jauss mine, near Dillsburg, made in 1888.

King and Jauss mines.—The King mine is situated on the east side of Fishers Run, about 3,300 feet north of the Price mine and 2,100 feet northeast of the Bell slope. The Jauss shaft (fig. 17) is situated near the east bank of the creek, 750 feet northwest of the King workings. The shafts of these two eastern mines were located by dip-needle indications. They were started in diabase, but at moderate depth both encountered ore associated with sedimentary rocks. The strata dip toward the north, so that it would appear that they must come to the surface south of the shafts. Nevertheless, the presence of these sediments would not be suspected from examination of the sur-

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[a] Frazer, Persifor, jr., Second Geol. Survey Pennsylvania, Rept. CC, 1877, p. 218.

face, because their outcrop is obscured by an overwash of diabase soil. Just north of the railroad track, however, on the west side of the creek and about 800 feet from the Jauss shaft, a patch of sediments may be inferred from the occurrence of sandstone fragments in the soil. It seems probable that these two masses of sedimentary rock may be connected, but the surface is covered to such an extent that nothing positive can be made out. It is entirely possible also that the sediments of the western patch may extend farther west than is indicated on the map (Pl. XX), for in this direction there is a broad swale in which the presence of diabase soil may be misleading as to the actual extent of the intrusive rock. The trend of the two sedimentary strips is in the direction of the Longnecker shaft on the west and toward an embayment in the outer boundary of the diabase area on the east. Along this general line the main mass of diabase is seen to be partly divided by intercalated sandstones and shales. Whether this separation becomes more or less extensive in depth can not be judged, but from the fact that in the Longnecker workings the bedded rocks appear to rise to a crest beneath the diabase, it seems possible that the dividing masses may extend farther along the strike underground than is apparent from surface indications, and that they may even connect with one another.

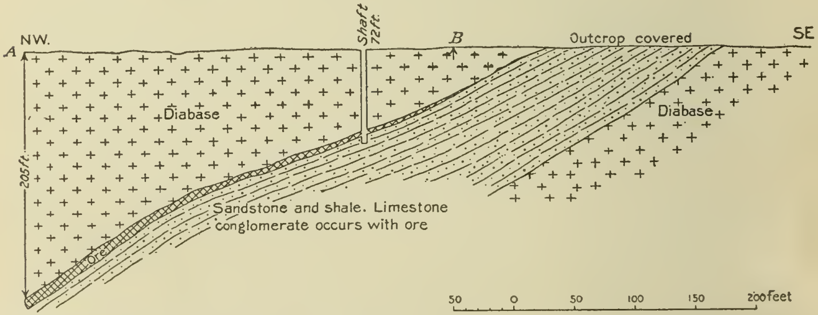

FIG. 18.—General structure section at Jauss mine, near Dillsburg (along line *A–B*, fig. 17).

It might be worth while to explore the western patch of sedimentary rocks mentioned above. If this is ever done it may be assumed that the northern contact with the diabase dips toward the north, as at the Jauss mine. On this basis the best scheme for proving the ground would be to sink shafts or bore holes just within the diabase area in order to catch the contact on the dip. The lower contact of the bedded rocks might also be explored both in this vicinity and south of the Jauss mine. A cross section showing the supposed structural relations in the vicinity of the Jauss mine is given in fig. 18. It is supposed that a section through the western sedimentary patch would be very similar.

The following notes concerning the King mine are abstracted from Frazer:[a]

The shaft, which was sunk in 1876, passes through 23 feet of soil and diabase, beneath which there was 9 feet of ore. Toward the east a drift 20 feet long encountered an oblique wall of diabase on the south side. Between this wall and indurated sandstones on the north the ore formed a wedge-shaped mass. From the end of this 20-foot drift a slope was opened upward until clay was encountered. The course of this slope (N. 3° E.) and its angle of inclination (22°) give the apparent direction and amount of the dip of the ore bed. From the bottom of the slope a drift was run N. 5° E. for a distance of 50 feet, following a fault showing slickensides. Along this gangway the fault rock is a broken-up mixture of sandstone and trap rock. About 20 feet east of the slope indurated sandstone exhibits a dip of 23° in a direction N. 40° W., but the dip of the vein is reported to be N. 10° W.

The Jauss shaft is situated just west of Fishers Run, at the eastern terminus of the branch railroad. The shaft was sunk at a point where the dip needle showed a marked magnetic attraction. About 72 feet of diabase was penetrated before the 7-foot ore bed was encountered. The floor of the mine is limestone conglomerate. As depth was gained the ore bed was found to thicken along the dip, and in the lowest workings, 205 feet below the surface, a large body of ore is reported. Stoping was carried about 30 feet above the point where the ore was cut through by the shaft. A survey made in 1888 shows the mine workings as extending 270 feet northwest of the shaft. In this distance the ore bed falls 133 feet, giving an average inclination of nearly 50 feet per 100, or about 30°. The dip appears to be somewhat steeper in the lower than in the upper workings.

Material on the waste pile shows that some of the ore at least has been formed by replacement of limestone conglomerate, though most of the material intimately associated with the ore is a light-green rock which appears to be an altered shale. Although no fragments of any rock except diabase are to be seen in the field south of the shaft, there can be little doubt that the sedimentary rocks which accompany the ore would be found beneath a relatively shallow cover of soil. On the geologic map (Pl. XX) a strip of sediments is indicated as extending southeast to the King mine.

Altland mine.—Just where the switch of the Bell mine joins the main track there are three shafts, two north and one south of the railroad. These constitute the Altland mine, concerning which the notes in the following paragraph are condensed from the description by D'Invilliers:[b]

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[a] Frazer, Persifor, jr., op. cit., p. 212.

[b] Ann. Rept. Geol. Survey Pennsylvania for 1886, pt. 4, 1887, pp. 1506–1507.

This mine lies northwest of the Bell mine and is opened by a shaft 62 feet deep, from the bottom of which a slope extends northward on the ore bed. This bed evidently lies geologically higher than the one worked at Bell's. Its outcrop was formerly worked a short distance south of the shaft. The shaft encountered ore at 57 feet and the slope is driven northward on a 23° dip for about 125 feet, the ore bed ranging from 4 to 7 feet in thickness. All along the slope the hanging wall seems to be a fine-grained trap, in places carrying small crystals of iron pyrites and here and there nodules of lime. But in the drifts at the bottom of the slope for 25 feet on each side an indurated slate rock wedges in between the trap and the ore, forming the hanging wall. The ore body seems to have a lenticular shape, as at the Cox mine, being thickest at the slope and thinning rapidly both east and west. The upper workings are confined to the vicinity of the slope, but at the bottom the ore bed has a workable thickness for a greater distance along the strike. The ore is rather micaceous.

From the surface distribution of the diabase, so far as it can be made out, the Altland ore seems to lie some distance below the bottom of the main diabase mass. It is possible that the trap mentioned by D'Invilliers is a thin eastward extension of the sill shown on the geologic map (Pl. XX) as ending west of the Longnecker tract. If this is the case, the Altland bed and the ore formerly worked at the Smyser pit probably correspond in stratigraphic position, and other ore shoots may exist beneath. Also, if the Smyser and Altland beds occupy the same stratigraphic horizon, the strike of the strata is diagonal to the contact of the main diabase, which is therefore slightly crosscutting in this vicinity, just as it is farther northwest, near the Underwood workings. From this conclusion it would seem worth while to seek for ore along the strike of the ore bed east of the Altland mine. At the contact with the diabase the structural conditions would be like those which have been deduced for the Bell deposit.

Smyser mine.—The Smyser open pit is situated about 450 feet west of the Altland workings, and, as already stated, the ore bed probably corresponds in position with that in the Altland mine. The Smyser deposit was opened in 1852, and 3,000 tons of ore are reported to have been won from it. Although the ore is said to have rested upon a saddle of diabase, the nearest diabase which can be determined from surface observations is the sill which passes north of the pit. This sill appears to end a short distance west of the Longnecker switch, though it is possible that it may extend somewhat farther east.

A small body of ore said to have been uncovered in the railroad cut just west of the road crossing, about 500 feet distant from the

Smyser pit, was never opened. It apparently lies in lower strata than those at the Smyser pit.

Bowlders of ore may be found in the cultivated field about 400 feet north-northeast of the Smyser pit and 200 feet north of the dwelling house. This locality is apparently inside the diabase area, but it seems possible that an irregularity in the bottom of the diabase mass has brought a small patch of sediments to the surface. If this supposition is correct, the occurrence of ore at this place is favorable to the view that ore deposits will be found in many places beneath the diabase when extensive explorations are undertaken.

Underwood workings.—The most productive ground of the Dillsburg field has been the northeasterly 35 acres of the Underwood property and the near-by portions of the McCormick tract on the north and the Logan tract on the east. On the Underwood tract there are five large open pits and several smaller excavations, all of which were exhausted previous to 1874, and four deep mines, which have been abandoned since 1887.

The southernmost of the Underwood workings are two pits situated about 500 feet northwest of the Smyser pit, on opposite sides of the north-south wagon road. These two openings are doubtless on the same ore body, which they have developed for about 400 feet along its course. Though the depth of the workings is not known, the ore must have been followed for some distance on a northerly dip, because there are depressions about 175 feet north of the western opening which appear to be the result of the caving in of underground workings. The narrow diabase sill which passes north of the Smyser pit touches the south side of the western opening, and just north of the pits is another sill which strikes northeast and west. The second sill can not be traced east of the wagon road, though it may extend for some distance in this direction. The two sills approach each other toward the west and finally unite. The main diabase contact, running from southeast to northwest, passes near the northeast corner of the eastern pit and the strike of the ore bed is evidently diagonal to this contact and also to the course of the southern sill, but it is nearly parallel with the trend of the northern sill.

The next openings, to the northwest, are two large pits in which the general line of excavation runs from the outlying sill on the southwest diagonally across to the main contact on the northeast. The boundary of the main diabase area crosses the northeastern of the two pits, which is said to have been the first mine opened in the Dillsburg field. These pits must have furnished a very large amount of ore. In 1873 a shaft was sunk in the bottom of the eastern pit (Derrick shaft), and is said to have passed through 25 feet of diabase and 28 feet of ore. The ore body is known to have been worked for a distance of 250 feet northeast of the shaft and it probably connects with the ore worked in the three deep mines lying immediately to the north. Between the open pits and the Underwood slope the ore bed apparently lies very flat. Limestone was encountered in the workings from the Derrick shaft.

About 600 feet northwest of these pits there is another large pit, the longer axis of which trends northeastward, nearly parallel with the diabase contact, which lies about 50 feet to the southeast. Waste, apparently derived from these workings, contains limestone and masses of garnet rock. A shaft was sunk about 50 feet beyond the southwest end of the pit, but whether or not ore was mined from this opening is not known.

Farther north there are two large pits between the one just described and the McCormick property line. In both of these the strike of the ore bed is slightly south of east. Nothing can be seen of the rocks which inclose the ore and it is not known to what depth the deposit was excavated.

Between the three western pits of the Underwood group and the edge of the diabase mass many small ore pockets were mined out at the surface, but the only important excavation in this part of the tract lies in the angle of the diabase boundary, about 300 feet south of the big McCormick pit. In the northeast corner of this excavation thin-bedded layers of baked sandstone may be seen dipping N. 80° E. at an angle of about 20°. The ore evidently passes under this sandstone, which therefore lies between the ore and the diabase seen on the east side of the pit.

Of the three deep mines on the Underwood tract which remain to be described, the oldest was opened by the so-called Underwood slope, the position of which is shown on the maps (Pl. XX and fig. 19). The following notes on this mine are condensed from Frazer's report:[a]

The slope sinks due north at an angle of 28°. Ore was not followed from the surface, but was reached at a depth of 26 feet. Diabase is exposed at the mouth of the slope, and the ore, where first encountered, is said to have been 18 feet thick. The dip of the ore beds is steeper in the lower workings than in the upper part of the mine. The foot wall is sandstone intermixed with limestone; the hanging wall is diabase. The distance between the walls varies from 6 to 30 feet. Three levels have been opened. On the first level, at 120 feet, drifts extend 100 feet east and west of the slope. The second level, at 180 feet, was opened 90 feet east and west, and the third level, at 200 feet, was opened 110 feet east and 120 feet west. The ore body was developed by raises about 20 feet apart, extending from level to level.

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, pp. 207–208.

Apparently referring to this same slope, D'Invilliers states in his 1886 report [a] that the workings were carried down 500 feet but were abandoned. He also says that the slope was carried down with the true hanging wall (that is, diabase) on top; but within a comparatively short distance the bed forked into an upper and a lower seam, with a wedge of slaty sandstone between. The gangways driven east [b] from the slope showed the ore being rapidly cut out by the convergence of the walls, and the drifts were continually kept turning toward the northeast in order to keep within the ore body. The best ore is said to have occurred near the place where the bed pinched; and where the bed is thickest the ore is mixed with slaty limestone layers and carries iron pyrites.

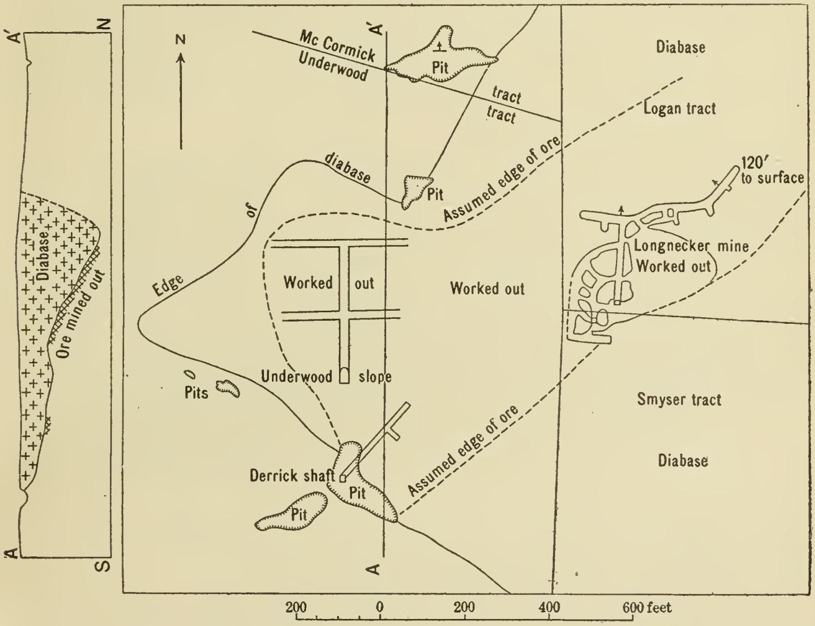

FIG. 19.—Plan and section of Underwood and Longnecker mines, Dillsburg, showing probable trend of ore bed.

In April, 1887, the mine was worked by a shaft 96 feet deep which is said to have passed through three ore beds—the first at 38 feet, 7 to 8 feet thick and rather lean; then 14 feet of sandstone; 8 feet of good ore; 26 feet of sandstone; and the bottom ore bed, 15 to 20 feet thick. These extensive workings lie entirely east of the old slope. As in the other mines, the foot wall is a hard white calcareous sandstone, and the hanging wall is diabase; but between the

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[a] Ann. Rept. Geol. Survey Pennsylvania for 1886, pt. 4, 1887, p. 1508.

[b] This word is west in the original, but the concurrence of the words "west" and "northwest" in this sentence makes it unintelligible as it stands.

walls lenticular masses of sandstone and slate wedge into the ore body. It is no doubt due to the swelling of such wedges that the three beds of ore were found in the shaft. The middle bed, which has been somewhat largely developed, is said to lie between beds of altered sand rock. In the lowest bed immense chambers have been opened where the ore swells locally; but where the bed is 15 to 20 feet thick it contains seams of limestone and bowlders of barren rock. The two upper beds are regarded as splits from the lowest or main bed. The mine may have furnished from 20,000 to 25,000 tons of ore, averaging 40 per cent of iron.

The last mine opened on the Underwood tract is described by D'Invilliers[a] under the heading "Longnecker mine," a name now applied to the mine on the Logan tract. The writer was not able to determine the location of this opening, which is said to lie a little east of the Underwood mine.

According to D'Invilliers, the shaft is 95 feet deep and the slope extending from its bottom has reached the McCormick line and is probably from 400 to 450 feet long. On the east four gangways have been driven toward the Longnecker mine, and from the bottom of the slope a gangway has been driven 150 feet west toward the Underwood mine. About 50 feet from the slope, in a stope above the west gangway, the ore in places is 20 to 30 feet thick. No new features are presented in this mine, and it may be considered that the ore is an extension 400 feet farther to the east of the Underwood bed. It may be, however, that there are two ore lenses which overlap each other.

The apparent relations of the ore and the diabase, so far as they may be judged from the recorded descriptions of the Underwood slope, are illustrated in the cross section (fig. 19).

The position of the section is 90 feet east of the Underwood slope and its direction is north and south.

Longnecker mine.—The mine now known as the Longnecker was formerly called the Logan mine. It was opened by the owner of the property, J. N. Logan, in 1874. The shaft was located from dip-needle indications, but 27 feet of diabase was penetrated before the ore was cut. Diabase soil and bowlders cover the surface near the mine, and it is evident that the ore must lie beneath the mass of this rock. Material on the mine dump shows that limestone conglomerate is present in the workings.

The ore bed is said to have been 20 feet thick at the shaft and to have averaged 10 feet in the mine. From the bottom of the vertical shaft, 51 feet deep, a slope toward the north starts at an inclination of 28°, but flattens somewhat as depth is attained. Mr. Logan

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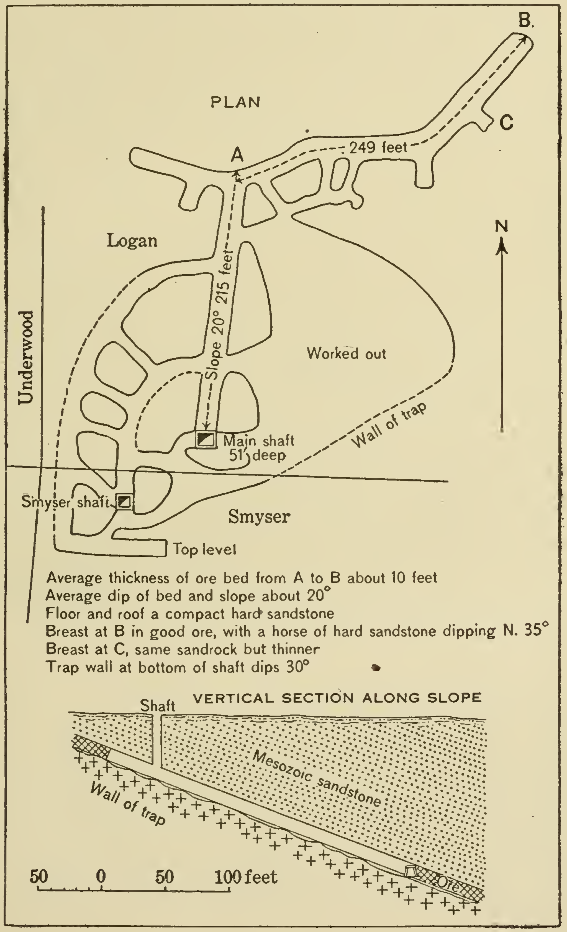
[a] Op. cit., pp. 1509–1510.

states that the workings extend about 300 feet north of this shaft and that the east drift of the lowest level is 190 feet long. The extent of the workings in 1885 is shown by the plan (fig. 20). Considerable work has been done since this survey was made. The vertical section which accompanies the plan does not correspond with the relations as they are stated above, but it is reproduced as



Average thickness of ore bed from A to B about 10 feet
Average dip of bed and slope about 20°
Floor and roof a compact hard sandstone
Breast at B in good ore, with a horse of hard sandstone dipping N. 35°
Breast at C, same sandrock but thinner
Trap wall at bottom of shaft dips 30°

Fig. 20.—Plan and cross section of Longnecker mine, on Logan tract, Dillsburg. From Ann. Rept. Second Geol. Survey Pennsylvania for 1885, p. 568.

originally drawn. From the inclination of the slope the ore bed should outcrop about 50 feet south of the shaft, but at this place the surface rock is undoubtedly diabase. The map shows that the underground workings reach a point fully 100 feet south of the shaft, so that the under side of the diabase must lie nearly flat south and southwest of the shaft, as it does in the ground south and southeast of the Underwood slope. In the vicinity of the shaft the bottom of the diabase takes an abrupt dip toward the north, as in the Underwood mine, so that both the Longnecker shaft and the Underwood slope appear to have penetrated the ore bed just at the angle where the steeper dip begins.

The very considerable extent of the ore bed shown by the Underwood and Longnecker workings furnishes a strong reason for believing that the Logan tract offers good ground for further development. The Underwood tract seems to have been completely worked out, though from the statement that the Longnecker workings extended north to the McCormick line it seems possible that the same bed of ore continues into the McCormick tract. A consideration of all the deep mines of this vicinity, however, suggests that the actual trend of the ore is toward the northeast, so that future discoveries are more likely to be made in the Logan tract than elsewhere. The boring which was made in the McCormick pit appears to be not deep enough to reach the extension of the Underwood ore. It is reported that a boring was made about 1,500 feet north of the Longnecker shaft, but no record of this work is available.

McCormick mines.—On the McCormick tract, situated north of the Underwood tract, there are three large pits and several small openings, all of which were abandoned before 1875. No large masses of diabase are present near most of the excavations, but the largest pit is situated at the western edge of the main diabase, about 200 feet north of the pit in the angle of the diabase boundary on the Underwood tract. This large pit is said to have been opened about 1850, and it is apparent from the fact that its area is nearly 12,000 square feet that it must have furnished a large amount of ore. The size of the vein is not recorded, but the longer axis of the excavation trends somewhat north of east, showing that the strike of the ore bed is in that direction. The position of the slope by which the mine was worked indicates that the strata have the usual dip toward the north.

Frazer states[a] that a shaft was sunk from the bottom of the pit to a depth of 140 feet, and that about 100 feet north of the pit a 20-foot slope was put down 60 feet on the vein of ore, which was 4 feet thick at the bottom. He gives the following record of a drill hole in the large pit:[b]

Record of bore hole No. 5, sunk in McCormick & Co.'s old bank.

	Feet.
Soil	8.84
Green sandstone	.17
Iron ore	.17
Gray sandstone	4.50
White sandstone	6.17
Reddish-green sandstone	12.08

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, p. 214.

[b] Op. cit., p. 216.

	Feet.
Black (?) trap	23.07
Gray sandstone	3.25
Iron ore	3.25
White sandstone	5.00
Iron ore	1.33
White sandstone	11.00
Limestone and flint	6.00
Limestone and fire clay	10.00
Red sandstone	14.00
Green sandstone	4.00
White sandstone	9.00
Green sandstone	3.00
Iron ore	2.00
Sandstone	2.00
Sandstone and ore	3.00
Limestone and flint	6.50
Ore and sandstone	.50
Green sandstone	5.00
White sandstone	5.00
Green sandstone	6.00
White sandstone	1.00
Gray trap	2.00
White sandstone	2.00
Limestone	3.00
Gray sandstone	4.50
Red sandstone	4.00
White sandstone	4.00
Red sandstone	1.00
White sandstone	4.00
Red sandstone	3.00
White sandstone	4.50
	187.83

It is evident from the above record that the mass of diabase which outcrops east of the pit does not dip beneath this ore body. The contact of the diabase with the stratified rocks might be supposed to be highly inclined and strongly crosscutting, except for the fact that about 400 feet toward the southeast, at the bottom of the Longnecker slope, the lower surface of the diabase is not more than 200 feet deep. It seems probable, therefore, that this lower surface dips rather gently toward the east or northeast. The most likely situation for a continuation of the ore body would be where the northward-dipping strata meet the eastward or northeastward dipping bottom of the diabase.

Though the drill-hole record shows thin layers of ore at five horizons and limestone at three horizons, it is not likely that strata equivalent to those containing the ore in the Underwood deep mines have been reached. If these beds continue with the same dip that they have in the Underwood slope, their position would be about 450 feet from the surface beneath the McCormick pit.

The second McCormick pit is a long, narrow excavation situated just north of the property line, about 200 feet farther west. (See fig. 21.) Nothing is known of this ore layer beyond the fact that it strikes slightly north of west. The pit is about 50 feet north of the nearest Underwood pit.

The McCormick long cut lies about 300 feet northwest of the large pit and 230 feet north of the excavation last mentioned. Though there are some small openings beyond, the long cut is the northernmost of the formerly productive mines of the Dillsburg field. The ore bed was opened for a distance of 325 feet along the strike and small openings were made at several places west of the main cut. The following notes are taken substantially from Frazer:[a]

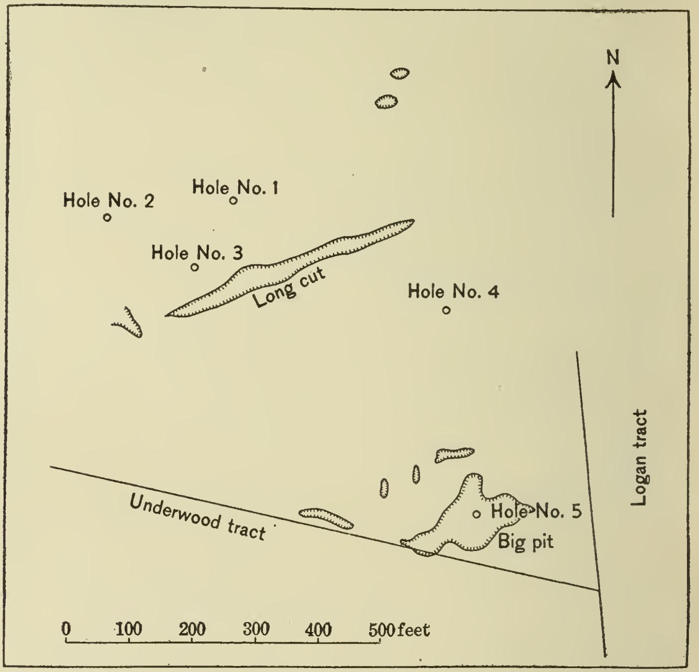

FIG. 21.—Sketch map showing situation of pits and test holes on McCormick tract, Dillsburg.

A dolerite, which occurs in this mine at the surface and appears to constitute the top rock of the ore, dips N. 5° W. from 27° to 34°. Two slopes were driven to find the ore. The upper one followed the vein in between well-defined walls at a normal angle to the inclination of the sandstone layers. The upper sandstone was continued in the deep, but the foot wall was cut out by a dike of diabase. The lower slope, of about 30° to 45°, was continued for 180 feet and passed through the ore, which appeared to be a very irregular deposit. In 1875 it was nearly exhausted.

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, p. 215.

Near the west end of the cut, fine-grained baked sandstone may be seen to form the hanging wall, but no evidence was found on the surface that diabase is present near the mine. The sketch map (fig. 21) shows the position of the several bore holes, the records of which, here given, are taken from Frazer:[a]

Record of bore hole No. 1, north of McCormick long cut.

	Feet.
Clay	4
Sandstone	8
Clay	2
Bastard limestone	9.5
Sandstone	9.5
Trap	9
Unknown, about	20
Brown sandstone	12
Iron ore	6
Sandstone	4
Lean iron ore	4
	88

Record of bore hole No. 3, north of McCormick long cut.

	Feet.
Clay	4
White sandstone	6
Red sandstone	7
Trap	17.5
Black and green sandstone	4
Brown sandstone	1
Green sandstone	8
White sandstone	1.5
	49

Record of bore hole No. 4, southeast of McCormick long cut.

	Feet.
Clay	2
Gray sandstone	8
Red sandstone	7
Unknown	10
White sandstone	7.5
Greenish-white sandstone	6.16
White sandstone	6.41
Green sandstone	2.83
Red sandstone	.50
Black (?) trap	16.08
White (?) trap	6.66
Ore	1.50
White sandstone	22.25
Green sandstone	13.16
Red and white sandstone	6.00
	116.04

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[a] Op. cit., pp. 215–216.

Hole No. 1, located about 110 feet north of the long cut, evidently penetrated the ore bed, which was mined from the surface. The record of hole No. 2 is not given. To judge from the known dip of the strata, hole No. 3, about 50 feet north of the cut, must also have passed through the horizon where the ore body should be, though no ore was reported. The $9\frac{1}{2}$-foot bed of limestone encountered in hole No. 1 probably outcrops north of hole No. 3. The record of hole No. 5 is given on pages 88–89.

The position of two small pockets of ore about 200 feet north of the east end of the long cut is indicated on the map (Pl. XX). A small quantity of ore is said to have been mined from a shaft 1,200 feet northeast of the long cut in the northeast angle of the crossroads. The position of this shaft is very near the boundary of the main mass of diabase.

Mr. Logan states that thin seams of magnetite, or of specular hematite, have been found at several points in the fields of his home farm, about half a mile northwest of the McCormick long cut. In this vicinity there are several minor bodies of diabase, but the shales and sandstones are not generally baked, as they are in the neighborhood of the old mines.

DIABASE INTRUSIONS WEST OF THE MINES.

The present examination of the geologic features of the Dillsburg field has revealed the presence of several bodies of diabase on the western slope of the hill on which most of the old mines are situated. The intrusions, which are four in number, appear at the surface as narrow bands, and though the relation which they bear to the inclosing rocks can not be observed, they are probably sills, more or less closely conforming with the bedding of the rocks which incase them. One of the bands is the westward and northwestward extension of the two narrow strips of diabase which cross the wagon road just south of the Underwood pits and come together about 500 feet west of the road. Where the two forks merge the band is 250 feet wide, though it becomes narrower toward the west. Its observed length is about 2,500 feet, but its western termination is not seen because of the deep soil in the meadows between the ore fields and Dillsburg. The three northern bands extend eastward nearly to the brow of the hill. The middle band runs northwestward for 800 or 900 feet, to a point where it appears to terminate, though this is not certain, for the surface débris in this vicinity is greatly mixed. The other bands may be traced toward the northwest until they are lost under the meadow soil. The northernmost band may be followed nearly to the wagon road, as shown on the map (Pl. XX).

On page 94 reasons are given in support of the suggestion that beds of limestone conglomerate which occur in the vicinity of Dillsburg may extend eastward and underlie the meadows between the town and mines. If any such continuity of conglomerate layers actually exists, they must traverse the ground occupied by the four diabase sills. From what has been learned concerning the geology of the Dillsburg deposits, it seems that the possibility of beds of limestone conglomerate being locally in contact with these intrusions makes all of this ground worthy of careful exploration. The absence of ore indications in the soil can not be considered conclusive evidence against the existence of ore bodies, as the ore is known to break down completely under long-continued action of the weather, and as on the hill slope the earthy material resulting from the superficial disintegration of an ore body would be hidden more completely than on nearly level ground because of the gradual downhill movement of the rock fragments and soil.

PRACTICAL CONCLUSIONS.

A practical question to which an unqualified answer can not be given is whether or not deposits of magnetic iron ore may yet be found in new localities in the Dillsburg district. It seems unlikely that new ore bodies will be discovered from surface showings encountered in tilling the soil, as in the earlier days of the district. Four of the ore bodies have been discovered by means of the magnetic dipping needle, and others may yet be found in the same way. In this connection, though no magnetic observations were made during the present investigation, it may be pointed out that in using the magnetic needle difficulties may arise from the attraction due to masses of diabase, for it is well known that this rock possesses magnetic properties in certain places. On the other hand, it seems possible that there may be ore bodies which the needle will not detect.

Whatever may be the truth on the foregoing points, their consideration is secondary to the understanding of the geologic features of the district, the presentation of which is the object of this report. From a purely geologic standpoint, deposits of ore like those which have already been worked might be expected to occur west of the ore fields along the borders of the several diabase intrusions near Dillsburg. The particular feature which distinguishes this part of the district and makes it seem more likely that ore deposits may be present here than at other places in York County where large masses of diabase occur is the existence of beds of limestone conglomerate. This rock is so closely associated with the ore bodies of the mines already worked that its presence must be regarded as one of the favorable conditions for ore occurrence, and where it comes into contact with diabase the chances for finding ore seem worthy of attention.

The mile-wide band of diabase which runs east and west just south of the ore fields narrows somewhat and assumes a northwesterly trend about 1 mile southeast of Dillsburg. The southern part of the town is underlain by the mass of intrusive rock, but here the band makes another turn, this time sharply toward the southwest, and it continues in this general direction for about 8 miles to its termination a mile or more northwest of York Springs. Southwest of Dillsburg minor indications of ore have been found at several points along the borders of this intrusion, and at two places small bodies of ore have been mined, as already noted. It is not possible to show the presence of limestone conglomerate at any of these places, though outcrops at several points show that beds of the rock are present beneath the low meadows between Dillsburg and Beavertown. There can be little doubt that the limestone conglomerate and diabase actually come together in several places, though the contact may lie some distance beneath the surface.

On the geologic map (Pl. XIX) the position of known outcrops of limestone conglomerate has been shown. At the quarry beside the Dillsburg-York Springs road, 1 mile southwest of Dillsburg, a heavy bed of the conglomerate dips toward the southeast, so that if the diabase, which lies east of the road, is a crosscutting mass, as seems likely, the stratum should come into contact with the igneous rock in this direction. Though baking of the sediments does not extend as far as the quarry, the presence of ore at the surface one-fourth mile to the south shows that solutions capable of depositing iron were active, and the chances that the conglomerate bed is mineralized at the contact seem worthy of consideration.

One mile southwest of the quarry mentioned in the foregoing paragraph, limestone conglomerate has been exposed at the eastern base of the diabase hill along an abandoned railroad grade. Here a considerable degree of metamorphism is shown by the presence of silicate minerals in the conglomerate, but no iron minerals have been introduced. The absence of ore in this place is possibly to be charged to the small size of the diabase intrusion lying immediately west.

It is impossible to discover the attitude of the strata between the outlying body of diabase just mentioned and the long dike which extends southwest of Dillsburg, but the rocks are much baked as the edge of the dike is approached, and beds of limestone conglomerate are likely to exist beneath the surface débris. In the event of a successful outcome of future explorations in other localities, it may yet be thought desirable to determine whether or not limestone conglomerate occurs in the vicinity of this southwest dike, and if it is found, to explore those places where it is likely to come into contact with the diabase. The existence of ore at the Bender mine and of ore indications about half a mile southeast of that opening shows at least that mineralizing waters were active in the neighborhood.

The dike or sill of diabase which crosses Dogwood Run northwest of Dillsburg has been traced in a northwesterly direction and found to connect with the wide intrusion south of the Grantham mines. Exposures of limestone very near the diabase are seen in the wagon road near the gristmill, in a railroad cutting near the upper end of the mill pond, and along the creek above the pond.

The attitude of the main diabase mass can not be made out, but in the railroad cutting it is evident that the limestone is cut across by several irregular intrusions of the igneous rock. The limestone where seen is not greatly metamorphosed, though the lack of red color in the soil indicates that the associated shales and sandstones are considerably altered. The diabase mass forms a prominent hill lying north and west of the creek, and from the contour of this hill it is judged that the intrusion does not form the floor of the broad valley east of Beavertown. In the area between the diabase hill and South Mountain there are no rock exposures, except in the quarry above Beavertown. This opening has been made about a sink, and 50 feet of limestone conglomerate has been exposed. Other sink holes, extending in a northeast direction, suggest that the same stratum continues for fully a mile in a northeasterly direction along the edge of the Mesozoic belt. Beds of conglomerate may come into contact with the diabase beneath the deep mantle of soil on the west and northwest slopes of the hill, so that this ground may be worth prospecting.

In the neighborhood of Dillsburg the body of diabase which has been under consideration lies well within the Mesozoic area, but 2 miles north of town it lies between Mesozoic strata on the southeast and Paleozoic limestone on the northwest. In a limestone quarry one-half mile south-southeast of the D. and M. Junction the limestone and diabase are seen almost in contact. The fact that the limestone shows no evidence of having been affected in any way by the diabase suggests that in this place the two rocks have been brought together by a fault. Though this structure can not be proved from the features to be seen in this quarry, there are strong reasons for believing that the boundary between the Mesozoic area and the older rocks of the valley and of South Mountain is formed by a profound fault for at least 25 miles southwest of the Susquehanna and for some distance east of that river. The probability that this fault exists and that movements have taken place along it since the intrusion of the diabase removes the contact with the Paleozoic limestones from consideration as a place in which ore bodies are to be expected.

Inasmuch as it is wholly impossible to estimate the thickness of the Mesozoic strata in the vicinity of Dillsburg or to judge either the distribution of the rocks which lie below these beds or the subterranean forms and courses of the intrusive mass of the diabase, no suggestions can be made concerning the possibility of ore deposits being present beneath the Mesozoic formations.

GRANTHAM MINES.

On the south side of Yellow Breeches Creek, near Grantham crossing, are situated three old mines, known as the Landis or Fuller, the Porter, and the Shelley. Outcrops in the railroad cuts and material on the mine dumps show that the deposits at this place occur in Mesozoic strata, which include beds of limestone conglomerate. North of Yellow Breeches Creek the bed rock is Paleozoic limestone, and just south of the mines diabase appears. This diabase is part of an intrusive mass of important size, extending westward and southwestward to the vicinity of Dillsburg and eastward for 4 miles or more to join a great mass of the same rock which forms the group of high hills between Dillsburg and Mount Airy. Just south of Grantham the intrusion is about 1 mile wide. Eastward from Rosegarden, its northern boundary is an irregular, waving line, which has not been traced in detail beyond Grantham. Near the mines the strata adjacent to the diabase are undoubtedly considerably disturbed, as is indicated by varying dips in the old workings. It seems, however, that the average ore-bearing beds decline gently toward the south and pass beneath the diabase, so that the latter forms a general hanging wall over the deposits. The Landis and Porter openings are situated just at the edge of the diabase, and at the Shelley mine a shaft is said to have penetrated diabase lying just above the ore. One mile up the railroad track from Grantham, at Rosegarden, diabase is seen along the tracks, and one-third mile farther west Paleozoic limestone appears only a short distance beyond the last outcrop of the igneous rock. Here, then, the diabase comes into contact with the older rocks. In the field south of the railroad débris revealed by gullies cut into the hill slopes shows the presence of sandstone beneath the diabase. These sandy beds can continue toward the west for a short distance only, for undoubted Paleozoic limestone is again observed very near the diabase on the highway just south of the crossroads. In the valley of the small brook which joins the creek at Rosegarden is an old prospecting shaft, situated at the south edge of the diabase mass. No indications of ore are to be seen in the material on the dump, but the amount of material thrown out indicates that considerable work was done at this place. The rock excavated is mainly a hard baked shale.

Northeast of Grantham, on the north side of the creek, is a mass of diabase which may have been separated from the main mass by the erosion of the creek channel. On the south side of this mass, in the wooded ravine about one-half mile east of the railroad, there is an old prospect pit in which baked sandstone occurs. Along the railroad track the diabase is to be seen in contact with Paleozoic limestone, but as the latter is not notably metamorphosed at this place it is thought that the contact is not an intrusive one, but that a fault has brought these two rocks together. This suggestion brings up the general structural problem presented by the northerly boundary of the Mesozoic belt throughout the State, discussion of which will not be attempted here.

In the fact that they occur between beds of limestone conglomerate and overlying diabase the ore deposits near Grantham resemble several of the deposits of the Dillsburg group, the same relation being observed in the Underwood, Longnecker, Jauss, Price, and Logan workings.

In the absence of any adequate data concerning the amount of iron ore that has been extracted from these mines and the degree of persistence shown by the ore bodies in the ground opened, it is difficult to judge whether prospecting in the vicinity for other deposits would be advisable or not. From a purely geologic standpoint conditions similar to those existing near the known ore bodies may be supposed to extend for a considerable distance both east and west of the old openings. The place to look for ore is evidently just beneath the diabase, and where conglomerate is present under the igneous rock ore is likely to be found. The most feasible way to make a test is by a line of drill holes located just within the boundary of the diabase area. Perhaps the most attractive scheme of prospecting would be to determine by means of the drill whether or not the deposits already known extend beyond the old workings in the direction of the dip.

The following data concerning the three old mines at Grantham are condensed from Frazer's report:[a]

The Landis mine was opened about 1863. A tunnel from the railroad and close to the banks of the creek enters a steep bank due south for 200 feet. Two drifts lead off west and east of the main tunnel. The hanging wall is diabase, dipping 24° N. 25° W.

Operations at the Porter mine were begun in 1855. In 1875 the excavation was reported to be about 40 feet deep and 14 feet below the water in Yellow Breeches Creek. Ore was loaded from the pit into carts. The ore bed is said to have been from 3 to 6 feet thick, to have been opened for 25 feet along the strike, and to have dipped 30° toward the creek.

At the Shelley mine 20 feet of diabase is reported above the ore. The ore bed was 10 feet thick and rested upon " Potomac marble "—that is, upon limestone conglomerate.

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, pp. 220–222.

Frazer regarded the inclosing rock of the Porter ore as probably Paleozoic limestone. Though the rock exposed in the near-by cutting along the railroad was thought by him to be "Auroral limestone," the present writer is confident that it is limestone conglomerate belonging to the Mesozoic belt. These strata dip toward the south at a low angle. A thin sill of diabase is seen in contact with the calcareous rock, which is considerably metamorphosed.

The following notes are given by D'Invilliers:[a]

The old Fuller or Landis mine is owned and worked by Mr. Shelley, who states that a shaft 80 feet deep passed through diabase to a chimney-shaped bed of ore dipping north-northeast. The same ore was struck 100 feet farther east by a 40-foot shaft, in which the ore also dips toward the creek. According to Mr. Shelley, there are four or five beds here, separated by short intervals of hard rock of a white color, and not unlike a baked slaty sandstone. In April, 1887, preparations were being made to sink on the outcrop of a lower bed showing about 100 yards south of the shaft. . .

Immediately across a narrow ravine to the east of this opening a large amount of ore was formerly raised by Mr. Fuller, and the operation is supposed to have been stopped owing to the occurrence of "Potomac marble," which cuts out the ore for a considerable extent through the mine and along the railroad. This rock shows largely through the field and along the track, where an abandoned cut developed a large body of soft surface ore, resulting from the decomposition of the bed, 5 to 8 feet thick, which was encountered in the bottom of the pit. Mr. Shelley says that there are 13 acres in this property through which no pinching in the ore beds occurs, so far as developed.

MINES SOUTHWEST OF WELLSVILLE.

The so-called "Minebank" workings are situated about 2 miles southwest of Wellsville, and about 6½ miles from the northwest boundary of the Mesozoic belt (Pl. XIX). The most prominent feature in the local geology is a mass of intrusive diabase, which appears at the surface in an elliptical area about 2½ miles long and 1 mile wide. This diabase is surrounded by shales and sandstones which are bleached and baked in the vicinity of the igneous rock. The general strike of the strata is northeast and southwest, and dips, wherever observable, are toward the northwest, usually at moderate angles.

The "Minebank" deposit appears to be a layer conforming to the strata by which it is inclosed. It has been opened by a series of pits and shafts extending from southwest to northeast for a distance of about 1,000 feet along the strike of the outcrop, and indications of

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[a] Ann. Rept. Geol. Survey Pennsylvania for 1886, pt. 4, 1887, pp. 1513–1514.

ore were found in explorations beyond the northeasternmost and largest mine, which is situated back of the schoolhouse. Although a narrow dike of diabase is said to have been encountered in one of the mines, the main intrusion lies some distance northwest of the ore cropping. The dip of the strata which inclose the ore is toward the diabase. The waste to be seen on the mine dump consists mainly of baked shale and fine-grained sandstone. Specimens may be seen in which joints crossing the stratification contain films of micaceous hematite. Lumps of solid ore may be found composed either of hematite and magnetite together, or of hematite alone. Some of the micaceous ore, which looks like specular hematite, yields a black powder instead of the red powder, which is characteristic of hematite, and is attracted by the magnet. A mass of similar ore is reported to have been mined out years ago from one of the Phoenix mines at Boyertown. Several blocks were noted which were composed of crystalline limestone and specular hematite with a sprinkling of chalcopyrite. A study of this material leaves little doubt that the iron mineral has been deposited through some process of chemical substitution. From the presence of the limestone it may be thought that the ore layer was formed by the replacement of a limestone stratum interbedded with the shales and sandstones which are the common rocks of the region. Whether this be true or not, there can be little doubt that the ore was introduced through the agency of hot water or gases, impelled by the adjacent intrusive mass of diabase. From the description given below it appears that the mineralizing solutions followed the narrow dike or sill of diabase which was encountered in the mine. Though showings of ore have been reported at several places in the vicinity of the large diabase mass, no minable body of ore has been discovered aside from the one at Minebank.[a]

The following data are abstracted from Frazer's report:[b]

Ore was first discovered in the vicinity of the present workings about 1805. Prospecting in 1872 led to the opening of the Altland shaft, which passes through 5 feet of soil, then 25 feet of light-greenish hard sandstone, below which a 6-foot bed of micaceous ore was encountered. Beneath the ore was blue to gray sandstone, similar to that above except for being harder. The ore was followed by a slope until a diabase dike was encountered. The dip measured on the sandstone is 31° to 35° N. 30° W. A second shaft was sunk in the same year, about 120 feet north of the first. In 1875 the gangways along the ore had a total length of about 500 feet. The ore lies between the sandstone in regular layers, varying from 6 inches to 7 feet in thickness, with occasional sandstone partings. It is in many places found cutting into the diabase. The boundary between the latter and the sandstone is very clearly defined. Ore had been found

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, pp. 231–238.

[b] Op. cit., pp. 235–236.

on the northwest side of the dike, but up to 1875 not in paying quantities. Sixty feet down the slope and 50 feet northwest of it both the sandstone and the diabase dip 30° NW. The diabase is here 4 feet thick. Thirty feet north of the shaft, 2 or 3 yards of rock in contact with the dike showed no ore, but the vein had been proved from this point to the surface. The ore is very micaceous.

BENDER MINE.

Near the York Springs road, about a mile southwest of Dillsburg, are two old pits from which iron ore was formerly extracted. One of these is situated east of the road, very near the boundary of the intrusive diabase, at the south end of an embayment of sedimentary rocks. No exposures of rock in place are to be seen near this opening, but limestone conglomerate and red sandy shale occur in the quarry beside the road less than one-fourth mile to the north. The mine is reported to have been a small one. The second mine, known as the Bender property, is located about one-fourth mile farther southwest, on the west side of the wagon road. This deposit is said to have been opened in 1849, in which year 200 tons of ore was extracted. In 1873 about 80 tons of ore was mined from a so-called pocket averaging 5 feet thick, lying under 7 feet of stripping. The mine was worked entirely by open pit.[a]

In the neighborhood of the Bender pit irregularly shaped masses of extremely hard and dense green rock may be found lying upon the surface or embedded in the soil. This flinty material is a much baked sedimentary rock, probably a limy shale or impure limestone in its original state. Some of the specimens examined are composed almost entirely of massive garnet; others contain considerable colorless pyroxene. Bowlders of this rock may be found in an area 300 to 400 feet long and about 100 feet wide. Soil derived from diabase is present on all sides of this patch, so that the strata with which the ore is associated evidently form an isolated mass, surrounded by the intrusive rock. The locality is near the west side of the diabase intrusion, here about one-half mile wide, which runs northeastward to Dillsburg and thence southeastward and eastward to join the great mass which forms the group of high hills between Stevenstown and Mount Airy. Southwest of Dillsburg this band of diabase has been followed for about 8 miles.

Flinty rock like that described above occurs on the east side of the diabase about a mile south of the Bender pit, but in this vicinity indications of ore are not known to have been found. From the occurrence of limestone conglomerate in the valley west of the Bender mine it seems possible that a bed of this rock may have been replaced in the formation of the ore deposit.

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[a] Second Geol. Survey Pennsylvania, Rept. CC, 1877, p. 226.

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